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Draft report for review

Development of a Regional Approach to Water Resources Monitoring Related to Energy Exploration and Development in Colorado

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Executive Summary

BLM is currently developing a National Monitoring Strategy to develop an efficient and effective process for monitoring land health on lands administered by BLM. To inform the ongoing development of the national strategy, the area encompassed by the Glenwood Spring Resource Area and the White River Resource Area were selected for development of a process for monitoring the effects of energy development on water resources. A three-phase monitoring plan was developed to guide the development of a monitoring program. Phase I is a synthesis and assessment of current conditions that capitalizes on existing but under used data sources, and incorporates existing water resources data and hydrologic models to evaluate the effects over time of surface disturbance. Phase II is the data collection process that uses information provided in Phase I to refine management objectives and provide a linkage to management decisions through targeted monitoring, adaptive management, and research. Phase III establishes priorities and strategies for regional and national monitoring, and facilitates coordination among other land management agencies and organizations. The phases are designed to be flexible and complementary, and the activities associated with each phase can be implemented or updated as new information, data, or tools become available. The monitoring framework guides an iterative process that is implemented incrementally, beginning with the highest priority management issues and related information needs, while building on the lessons learned and coordination among administrative levels.

Examples of network design and monitoring practices are presented. An initial example of the integration of water-resources disciplines is presented. In addition, an example of how the Regional Monitoring Framework is used in the process of adaptive management is outlined. (note to reviewer: based on feedback after the initial review these example would be expaneded aas per review comments from BLM).

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Background and Objectives

Recently, the BLM initiated the development of a National Monitoring Strategy to improve the efficiency and effectiveness of the Bureau's inventory, monitoring, and assessment efforts. The BLM faces a substantial challenge in developing and implementing monitoring programs that are effective and efficient across multiple scales, and capable of satisfying multiple institutional and legal requirements associated with environmental compliance and land-use planning. The overall goal of this project is to develop, with BLM, a practical approach to integrated water-resources monitoring related to energy development that capitalizes on existing monitoring programs and readily available data and information. The monitoring strategy will include protocols for reporting on resource condition and the effectiveness of management actions at the local, regional, and national levels. As a part of this effort, an evaluation of the Bureau's monitoring efforts in relation to energy development was initiated by an energy team. A subset of the energy team is the Water Resources Regional Energy Monitoring Strategy Subgroup (WREMSS), which is evaluating the current data-collection process and analysis used to inform managers about activities related to energy development and water resources.

The primary conclusion of the WREMSS was that current monitoring generally focused on compliance and effectiveness monitoring at the local lease level (Falise et al. 2005). The WREMSS identified several other issues that limited the effectiveness of current monitoring activities. Frequently, clear monitoring objectives were lacking. Information was incomplete, not analyzed or accessible, or was not used to evaluate or validate decisions or management actions. Inconsistencies among field offices precluded larger status and trend analysis. Finally, current monitoring does not have a defined link to management and policies because management targets and thresholds have not been clearly defined.

For the purposes of this project region is defined as two adjoining BLM Resource Management areas. The Regional Monitoring Plan is being developed around the White River Resource Area managed by the BLM office in Meeker, Colorado and the Glenwood Springs Resource Area managed by the BLM office in Glenwood Springs, Colorado (figure 1). Information from discussions with BLM staff and previous water-resources investigations will be used to help identify potential key variables for assessment, to identify interactions among stressors and indicators to determine appropriate scales for description, monitoring, and adaptive management. Data available from existing monitoring activities (BLM, USGS, and other State and local agencies) relevant to monitoring effects of energy development are identified.

Information from these different perspectives describes a framework for monitoring that is applicable to the region of interest. The approach allows for scalability of the monitoring framework and describes aerially and vertically nested monitoring approaches and networks, coupled with focused studies of controlling processes, to provide understanding at multiple scales, address spatial and temporal variability in key assessment variables, and result in regionally comparable datasets. This approach addresses threshold measurement values needed to inform management actions. Although a logical next step, we do not propose here to conduct extensive and detailed spatial analyses or to implement monitoring of environmental effects of energy development. Rather, the monitoring plan describes an approach in sufficient detail to facilitate implementation.

Seven-step Framework

The seven-step framework, adapted from Mulder et al. (1999), is used for perspective in the proposed phased approach:

1. Specify monitoring goals and objectives
2. Characterize stressors (anthropogenic) that affect the parameters of interest.
3. Develop regional questions and conceptual models to describe how, and through what pathways, anthropogenic stressors affect receptors.
4. Suggest indicators to measure the effects of stressors, and define information availability and needs.
5. Estimate the sensitivity of indicators to detect change, to guide final indicator choice and sampling design.
6. Describe a process by which management can identify thresholds of change requiring a management response.
7. Identify clear connections between the overall monitoring program and the management decision process.

By using the seven-step framework, the monitoring plans can build on the lessons learned from the success and failures of previous monitoring programs by including critical components (Mulder et al. 1999). In addition, it provides a common framework to evaluate the potentially different objectives and resource management issues in the focal area.

BLM Objectives

The following objectives identified by BLM were used as a guide for this report. These objectives were developed to ensure that the monitoring plan developed for the focal areas will provide information useful to BLM's national monitoring strategy.

1. Develop a generally applicable methodology for BLM regional monitoring programs using the seven-step process outlined above.
2. Implement that methodology to produce a report that prototypes a specific BLM regional monitoring program for the White River and Glenwood Springs Field Offices.
3. Provide BLM with feedback and recommendations based on the experience of developing the methodology and applying it to a specific region.
4. Develop recommendations that will aid BLM in selecting indicators and adopting appropriate thresholds for management response.
5. Recommend how the product can be integrated within the land use planning process.

Colorado BLM meeting summary

Additional objectives and priorities were discussed at the July 2006 meeting at the White River Field Office, which included about 35 representatives from BLM, Colorado Division of Wildlife, The Nature Conservancy, and USGS. This was the initial meeting to identify issues related to the potential effects of energy development on water resources in the region defined by the Glenwood Springs and White River Resource Areas. The issues listed reflect an emphasis on connecting the issues identified to management questions faced by BLM land managers. Issues identification is the first step in developing a Regional Monitoring Framework to assess the effects of energy development on water resources. The process identified potential stressors from energy development and receptors in the hydrologic and aquatic ecosystems that may be affected. The list, presented as questions, provides the basis for development of a Regional Monitoring Framework that encompasses these two Resource Areas.

Issues/Questions related to land-management:

- What is the context for evaluating changes (both anthropogenic and natural)?
- What are the implications of landscapes changes to water quantity, quality and watershed function?
- What are the indirect and effects over time of energy development at local and regional scales?
- How can changes to water quality and quantity be evaluated (identify surrogates)?
- How can the threshold of acceptable change be defined? How to quantify effects on water-quality standards violated or beneficial uses?
- How to determine BMP effectiveness?
- How do we implement performance based mitigation and monitoring?

Issues/Questions will be related to tracking surface disturbance:

- How to address the progression of surface disturbance?
- At what point do we determine what information is needed for what purpose?
- What are there important environmental factors to consider in siting new gas wells?
- What information is needed to track surface disturbance?
- What environmental factors need to be considered in locating new energy development?

Issues/Questions will be related to involvement with state and other federal agencies.

- State agencies are critical to the process

  - Sampling sites operated
  - Personnel involved
  - How does the monitoring plan support states responsibilities under the Clean Water Act?
- Acknowledge BLM MOU with States to minimize NPS pollution
- Will Section 7 consultation focus the depletion and produced waters issues for depletion thresholds for T&E fish?

Issues/Questions will be related to characterizing baseline conditions and anthropogenic effects

- How to differentiate natural variability related to climate, geology, and other factors from industry effects?
- Characterize the type of oil and gas development, e.g. conventional/oil shale/CBM and develop a monitoring framework to address the differences in development.

Issues/Questions will be related to tracking effects on ground water:

- Will development of oil and gas wells and oil shale have the potential to affect aquifers?
- Is there a hydrologic connection between affected units and used aquifers?
- How does re-injection ultimately affect other aquifers?
- How does fracturing potentially affect flow in and between aquifers?
- How does overspray or leakage from retention ponds affect shallow ground water?

Issues/Questions will be related to tracking effects on ground-water surface-water interactions:

- Does the development of oil and gas have the potential to effect base flow of springs and streams?
- How can small isolated springs that support intermittent stream flows be protected?

- What will be the residual effects of retorting oil shale on surface and ground water quality?
- How can effects to spring flow and water quality be monitored at site and regional scales?

Issues/Questions will be related to tracking effects on surface water:

- How can effects of flow modification and water quality alteration on aquatic habitat best be measured?
    - At what level of impacts do we reach impairment of beneficial uses?
- How can sediment and salinity best be monitored to quantify energy impacts?
    - At what level of impacts do we reach impairment of beneficial uses?
- How can impacts to stream morphology and stream stability best be measured?
    - At what level of impacts do we reach impairment of beneficial uses?
- Will water be imported to the Piceance area and what will be the effects?
- How can the source of impairment to beneficial use be identified?
- What are the cumulative effects of surface disturbance in a watershed on sediment, salinity and stream biology?
- How should the results be compared to aquatic endpoints?
- How should stream sediments be measured?
    - How should the results be compared to the state of Colorado narrative sediment standards?

The Regional Monitoring Framework needs to address the issues associate with the categories listed above: land-management questions, tracking surface disturbance, involvement with state and other federal agencies, characterizing baseline conditions and anthropogenic effects, ground water, ground-water surface-water interactions, and effects on surface water.

Monitoring Plan for Colorado

Here we report on a monitoring plan developed for the Colorado focal area, which was designed to meet the objectives, criteria, and needs identified by BLM and other stakeholders. The monitoring plan is defined as a process or framework that can be used to guide the development of monitoring programs by BLM field offices. The design of the plan was based on the information needs identified for the area under the jurisdiction of the White River and Glenwood Springs Field Offices (fig. 1). Although the priority management issues for the focal area were used to guide plan development, it was designed with enough flexibility to be applied to any BLM field office.

The plan begins with a discussion of water-resources monitoring frameworks and assessments which were reviewed as a part of developing the plan. The monitoring plan includes sections on surface-water (streamflow, water-quality, and stream biology), groundwater, surface disturbance and a case study on watershed modeling. Each section outlines data sources, steps related to Phases I, II, and III and expected products. Issues related to each discipline are discussed and approaches for developing information for characterization, compliance monitoring, and trend analysis are outlined.

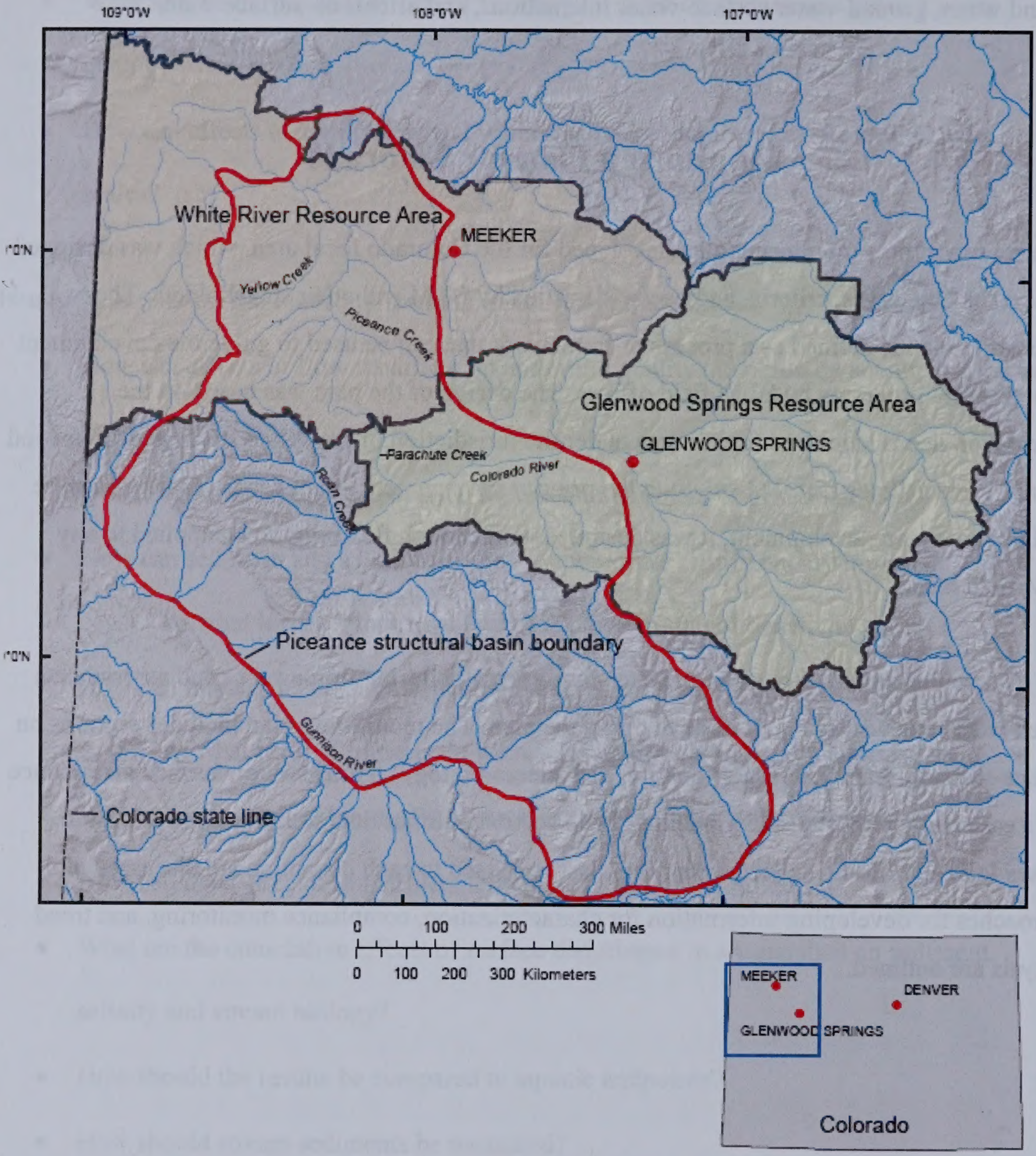

109°0'W
108°0'W
107°0'W
°0'N
°0'N
White River Resource Area
MEEKER
Yellow Creek
Piceance Creek
Glenwood Springs Resource Area
GLENWOOD SPRINGS
Parachute Creek
Colorado River
Roan Creek
Piceance structural basin boundary
Gunnison River
Colorado state line
0 100 200 300 Miles
0 100 200 300 Kilometers
MEEKER
DENVER
GLENWOOD SPRINGS
Colorado

Figure 1. Study area for the Colorado BLM monitoring program. White River and Glenwood Springs field offices (in green) comprise the focal area.

Water Resources Monitoring Frameworks and Assessments

Monitoring programs for water resources generally have two objectives, one of which is to assess the status and trends in the quantity and quality of water and the second of which is to link status and trends to natural and human factors that affect quantity and quality (Gilliom and others, 1995). Energy development is one of the more visible human activities with the potential to affect water resources on a regional scale in the western U.S. Energy development consists of exploration activities and subsequent production and transport of the resource. Basins like the Powder River in Wyoming have already experienced widespread energy development, but others like the Piceance Basin in Colorado have not. Superimposed on regional energy development is natural variability in water resources resulting from regional gradients in topography, geology, climate, and vegetation which can complicate the understanding of how energy development affects water resources.

One of the most important issues facing the Bureau of Land Management is how to understand and possibly forecast the effects over time of energy development on regional hydrologic systems in the western U.S. so that widespread degradation of the resource can be minimized or avoided. Regional forecasts of those effects based on local-scale monitoring networks would be difficult, if not impossible, without an understanding of the regional context in which those networks exist. Thus, a regional framework for monitoring water resources in the western U.S. is needed that provides context for distinguishing between natural and human controls on water quantity and quality and that facilitates spatial and temporal up-scaling of local monitoring results.

Monitoring for scientific understanding in support of land management requires a design where sites are selected to represent certain human activities, environmental settings, and hydrologic conditions during different seasons, and to represent interannual variations in hydrology. Monitoring sites may be selected to assess the effects of land-use practices and resulting contamination in streams and aquifers. A monitoring design requires ancillary information on land use, chemical sources of contamination, natural landscape features, and hydrology. Such a design also requires the collection of various monitoring data. For example, over different seasons, water-resources assessments generally show low concentrations of contaminants, such as pesticides, in streams for most of the year—lower than most standards and guidelines established to protect aquatic life and human health. However, the assessments also show pulses of elevated concentrations— commonly 100 to 1000 times higher— during times of the year associated with rainfall and chemical applications than during other times of the year (Gilliom and others, 2006). Such pulses could result in Clean Water Act violations, affect aquatic life at critical points in the life cycle of aquatic organisms, and also water supplies for short periods. These conditions cannot be described in a meaningful way unless repetitive, time-and streamflow-dependent, monitoring is conducted at given sampling locations, with a substantial part of that sampling focused at times that are prone to large water-quality changes. Multiple samples are less critical in ground water as changes occur more slowly and generally are less influenced by seasonal conditions or individual hydrologic events (Hirsch and Hamilton, 2006).

Monitoring programs need to characterize hydrologic gradients resulting from different geologic or climatic settings. The geologic setting—whether alluvial deposits, sandstone, or igneous rock—affects how readily water and associated contaminants move over the land, into the ground, and between aquifers. For example, geologic formations are an important part of the hydrologic system of the Piceance Basin because all or part of them are aquifers. The aquifers transmit and store water and form a major part of the overall flow system. Aquifers associated with the oil shale in the basin have several permeable zones, resulting from fractures and interconnected pores. Geologic beds that are less permeable than the aquifer zones tend to retard ground-water movement but not completely. Similarly, climate can have profound effects on water quantity and water quality. Streamflow and the rate of recharge to aquifers varies seasonally and geographically in the Piceance Basin where precipitation generally increases with elevation and ranges from about 12 to 20 inches per year (Taylor, 1987).

Water quality and biological systems are closely interconnected. Aquatic organisms, such as algae, macro invertebrates, and fish are susceptible to water-quality degradation. In Piceance Creek, Covay (in Taylor 1987) defined a downstream gradient in species composition of benthic–invertebrates related to increased dissolved solids and stream substrate. Water-quality assessments depend on biological monitoring and determinations of how biological response varies among diverse hydrologic settings and conditions related to land use.

Targeted monitoring and the resulting scientific understanding help to answer questions, such as ‘‘Why do water-quality conditions occur and when? Do certain natural features, land uses, human activities, and management actions affect the occurrence and movement of certain contaminants? Is water quality getting better or worse?’’ The information helps decision-makers to more cost-effectively: (1) identify and prioritize those streams, aquifers, and watersheds most vulnerable to contamination and in need of protection; (2) target management actions to specfic sources and causes of pollution; and (3) evaluate the effectiveness of those actions over time (Hirsch and Hamilton 2006). Targeted monitoring may be associated with compliance monitoring, synoptic characterization of streamflow and water-quality conditions (Tobin, 1993 and Ortiz, 2000), and the monitoring of impacts to a watershed over time (trend monitoring) (Vaill and Butler, 1999). Another approach is probabilistic monitoring, in which sites are selected randomly across a certain region. This is a useful method for obtaining an unbiased, broad geographic snapshot of ''whether there is a problem'' and ''how big the problem is.'' Targeted and probabilistic monitoring designs are both important for answering different types of questions and for providing different types of information that are critical for understanding the ambient resource. Effective decision-making requires recognition of, and commitment to, several fundamental hydrologic tenets that underpin all monitoring (Hirsch and Hamilton, 2006). The following discusses these tenets as presented by Hirsch and Hamilton (2006).

Hydrologic Cycle:

Water-quality data must be evaluated in a ''total resource'' context, including all components of the hydrologic cycle. Surface water, ground water, and the atmosphere are all connected, and the interactions among them are crucial to determining streamflow; ground-water recharge, storage, and discharge; the fate and transport of contaminants; and chemical and biological quality. Ground water can be a major contributor to rivers, streams, and other surface-water bodies; contaminated aquifers that discharge to waterways can, therefore, become nonpoint-pollution sources. Quantifying ground-water contribution to surface water is essential for meeting Clean Water Act goals. Exclusion of groundwater monitoring may prevent a full accounting of all available sources and may limit the effectiveness that BMPs could have in future stream protection and restoration efforts. Similarly, surface water can be a major contributor to ground water and, therefore, a major nonpoint-contamination source for aquifers, particularly where high-capacity, public-supply wells are located near rivers and streams.

Hydrology Controls Water Quality:

Only part of the water-quality story can be told from monitoring for concentrations of chemical constituents in water without the quantitative hydrologic context and calculation of fluxes. A large part of the variation in water quality at a given location is determined by streamflow. Amounts of contaminants measured at a sampling site tributary can increase substantially from year to year simply because of high stream flows during wet environmental conditions. Water-quality data must be evaluated in concert with water quantity. Concentrations and types of contaminants and their potential effects on ecosystems and drinking-water supplies vary over time and depend largely on the amount of water flowing in streams and the amounts and directions of ground-water flow. Contaminant concentrations vary greatly between low and high flows, during different seasons of a year, and during different hydrologic regimes—such as periods when rainfall, snowmelt, or ground-water inflow dominates river flow. It is critical to monitor water quality under these different hydrologic conditions, and to evaluate the load of material that is transported in a stream and river and delivered to receiving bodies, such as lakes, reservoirs, estuaries, and bays.

Hydrology Controls Timing Of Water Issues

Changes in water quality in surface-water systems can be relatively quick—within days, weeks, or months. Or, changes can be relatively slow, such as in aquifers where changes can take decades because of slow ground-water movement. Without comparable data collected over time, long-term trends cannot be distinguished from short-term fluctuations, and natural fluctuations cannot be distinguished from the effects of human activities. Consistent and systematic long-term monitoring also is critical to evaluating whether environmental and management strategies are working, and for choosing the most cost-effective resource-management strategies (Hirsch and Hamilton, 2006).

To evaluate the effects of energy development on water resources over time long-term monitoring is needed to provide hydrologic characterization within a historical hydrologic context. This is particularly true for changes in ground-water and sediment quality, which may not be evident for years or even decades.

A long-term, hydrologic context is important when evaluating effects of energy development and management practices. For example, in regional aquifer systems where saturated thicknesses can be large and ground-water residence times can be long, changes in ground-water quality in response to contamination may occur slowly over decades or even centuries (Fogg and LaBolle, 2006). Those gradual trends in water quality are not easily recognized in the absence of long-term monitoring. Just as contaminant concentrations may gradually increase over long time periods, so to may long time periods be required to attenuate or flush contaminants from regional aquifer systems once they become contaminated. Thus, long-term monitoring at critical locations in the flow system is necessary for providing early warning of widespread regional contamination to minimize protracted remediation scenarios.

Shallow aquifers with shorter ground-water residences times, such as alluvial systems, respond much more quickly to contamination than regional aquifers, however even in those shallow systems years or decades may be required to attenuate or flush contaminants (McMahon and Bohlke, 1996).

The long-term, hydrologic context is also important to sort out the effects of natural variability from the effects of man's activities. Natural events such as floods or drought often can mask shorter term, human actions with the occurrence of particularly wet or dry years. Only after understanding the patterns within the historic hydrologic record are we likely to recognize any underlying changes that are taking place due to man's activities.

Predicting Hydrologic Response To Energy Development:

The development and verification of predictive tools and models is an essential step in understanding and successfully managing the impacts of energy development on water resources. Such tools are needed to extrapolate or forecast conditions to unmonitored, yet comparable areas, both in space and in time. During a time of increasingly diminishing resources, it is unrealistic to expect to monitor our water resources directly in all places and at all times. Moving from monitoring to modeling ultimately provides for regional assessments of water resources.

The use of predictive tools helps to prioritize contaminant sources and to understand the importance of factors affecting water resources, including surface disturbance, ground-water reinjection, landscape features, and hydrologic transport. Predictive tools can help estimate conditions that often cannot be directly measured, such as the effects of specific management practices or the percentage of contamination in a stream that originates from different sources. For example, the Gulf of Mexico experiences low concentrations of dissolved oxygen each spring and summer largely as a result of large amounts of nitrogen delivered by the Mississippi River, which in turn promotes excessive growth of algae and other nuisance plants and potentially can harm the fisheries. The USGS model SPARROW (SPAtially Referenced

Regression On Watershed attributes) shows that a considerable amount of the nitrogen delivered to the Gulf of Mexico originates in distant watersheds in the Mississippi River Basin, such as in Ohio and Tennessee (Alexander et al., 2000).

In addition, models can be used to estimate probabilities that concentrations of selected compounds will exceed a specific value, such as a drinking-water standard or an aquatic-life guideline, at a particular location. The SPARROW model has been applied, for example, to predict in-stream concentrations of phosphorus in streams across the U.S. that meet the EPA recommended goal 0.1 milligrams per liter to control excessive growth of algae and other nuisance plants. Ground-water modeling has been used to predict the presence of atrazine in shallow ground water within agricultural areas across the nation; model results show the highest detection frequencies of atrazine in parts of the Midwest, Great Plains, Pacific Northwest, and Mid-Atlantic regions where atrazine is heavily used in hydrologic settings that favor the transport of pesticides to ground water (Stackelberg et al., 2006). Similarly, a nitrate model used to assess the risk of nitrate contamination in shallow ground water across the U.S. shows that nitrate concentrations are expected to be lowest in shallow ground water underlying areas with low inputs of nitrogen and poorly drained soils, such as in parts of the southeastern Coastal Plain, and highest in areas with high nitrogen inputs and well-drained soils that overlie unconsolidated sand and gravel aquifers, such as in the High Plains of northeastern Nebraska and the western U.S. (Nolan et al., 2002). Although results from these models may not be used directly when making policy decisions, they provide critical insights into the locations of more vulnerable water resources, and help to prioritize where and how we commit resources to remediation and future monitoring.

The details associated with the water-resources monitoring framework and assessments are distributed between the three-phased approach described in the Monitoring Plan Overview. It is expected that some aspects of the modeling plan will carry over between each phase of the monitoring plan while some, for example, predicting hydrologic responses will be confined to a particular phase, in this case Phase 3.

Monitoring Plan Overview

To best address the needs and constraints of BLM, a iterative three-phase approach is proposed that includes successive stages building on the information and experience gained from earlier stages (Fig. 2). In each phase, monitoring is gradually expanded, beginning with an initial emphasis on greater use of existing data, spatial analysis, and predictive modeling, and ending with a fully integrated and coordinated monitoring program in the third phase. This three-phased approach allows for rapid implementation of a program to assess status and trends, while gradually expanding the scope with feedback from an adaptive monitoring framework that is linked to the BLM national monitoring program.

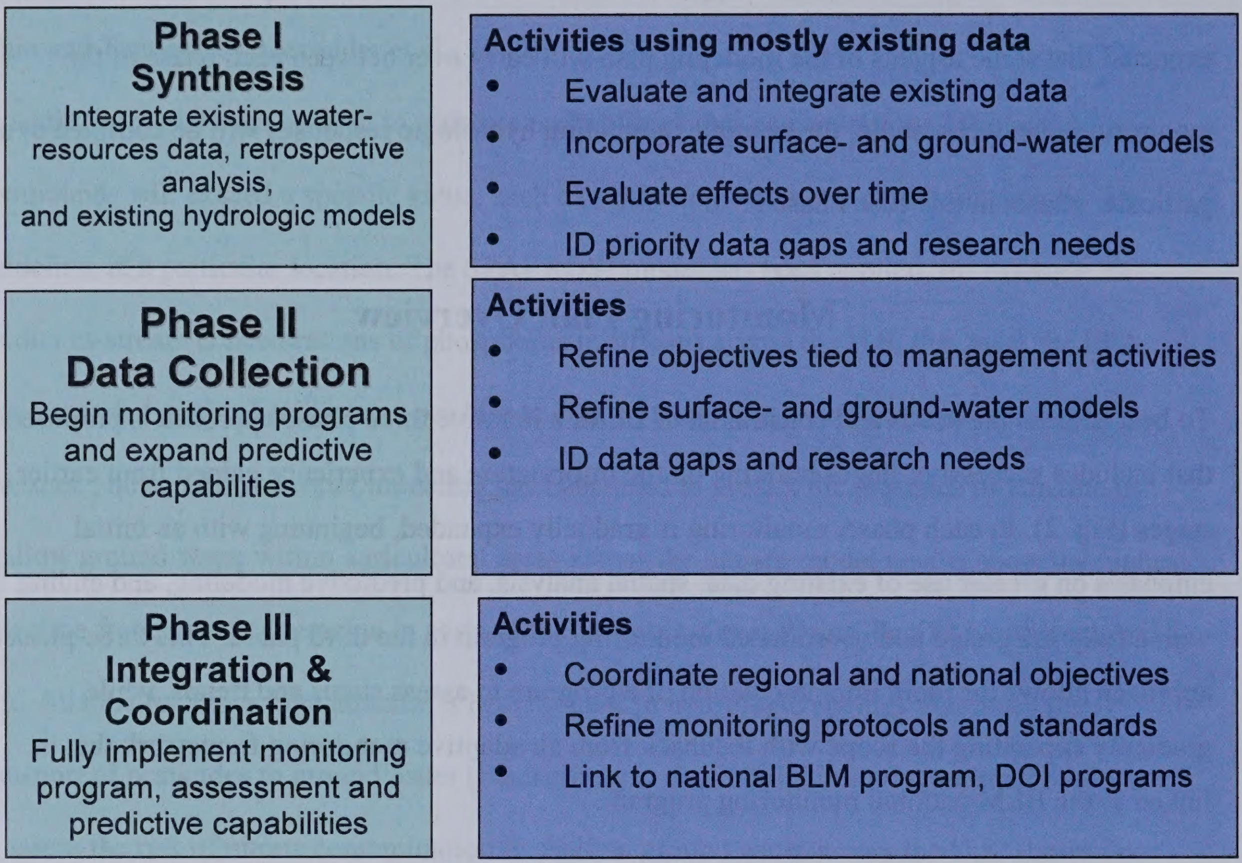

Phase I
Synthesis
Integrate existing water-resources data, retrospective analysis, and existing hydrologic models
Activities using mostly existing data
• Evaluate and integrate existing data
• Incorporate surface- and ground-water models
• Evaluate effects over time
• ID priority data gaps and research needs
Phase II
Data Collection
Begin monitoring programs and expand predictive capabilities
Activities
• Refine objectives tied to management activities
• Refine surface- and ground-water models
• ID data gaps and research needs
Phase III
Integration & Coordination
Fully implement monitoring program, assessment and predictive capabilities
Activities
• Coordinate regional and national objectives
• Refine monitoring protocols and standards
• Link to national BLM program, DOI programs

Figure 2. Overview the BLM water-resources monitoring plan.

In Phase I, a synthesis is conducted by: 1) capitalizing on data from existing monitoring that is not being used currently or are underutilized, 2) incorporating existing hydrologic models, 3) addressing landscape-level effects of surface disturbance using spatial analysis and GIS capabilities, 4) evaluating historic water-resources data (retrospective analysis), and 5) identifying critical information gaps that require additional surveys, models, and/or research. Phase I provides an initial assessment of the current status and trends of energy development and the effects on water resources, as well as an in-depth evaluation of the current state of knowledge and data quality. Phase II includes a data collection process that is informed by Phase I retrospective analysis. In addition, Phase II activities refine management objectives and provide a linkage to management decisions through targeted monitoring, adaptive management, and research. Phase II also expands the predictive modeling developed in Phase I by modifying or creating hydrologic and stream habitat models for priority issues based on new data, as well as adding or expanding the monitoring network and research to test predictions, assumptions, and critical information gaps identified in Phase I. Phase III establishes regional and national priorities, strategies, and guidelines for monitoring. This is based, in part, on information derived from the application of Phases I and II to determine common priorities among several field offices and larger regions. In addition, collaboration among other land management agencies and organizations (e.g., FWS, NPS, USFS, Colorado Department of Natural Resources and the Colorado Department of Health and Environment) will improve the efficiency and effectiveness of monitoring programs by reducing duplication of efforts and creating standard monitoring protocols for priority management issues that span multiple jurisdictional boundaries (e.g., field offices, agencies) to allow for analysis beyond local scales. Collectively, the three phases are designed to ensure that quality information is available to meet the priority monitoring and evaluation requirements of BLM.

The seven-step framework (Mulder et al. 1999) will guide program development at each phase (Table 1). Initial identification of objectives, stressors, conceptual models, and indicators will be achieved in Phase I, but will be refined and expanded in Phases II and III. The primary difference between the phases is in the types of activities that are applied to the seven-step framework. By dividing the monitoring plan into three complementary phases, the goal is to create an adaptive monitoring process that expands incrementally as knowledge increases. Information that guides the process includes regulatory requirements, streamflow and water-quality trends (surface and ground water), trends in stream biology and aquatic habitat, experience in implementing/expanding surveys, and predictions that can be tested in an adaptive monitoring framework. This will allow for rapid implementation of a program that is not prohibitively complex or unwieldy, yet is scientifically sound and uses the best available information at each stage of development. By gradually expanding and adapting the monitoring program, the likelihood of costly mistakes will be reduced. Finally, it allows for step-wise incorporation into existing BLM protocols without creating unnecessarily complex changes in existing operating procedures that could excessively burden field office personnel or slow implementation.

Table 1. Relationship between seven-step framework (Mulder et al. 1999) and activities associated with each monitoring plan phase.

Seven-Step Framework	Phase I	Phase II	Phase III
Specify goals	Develop initial goals	Refine/expand goals tied to management options	Coordinate regional, national, and interagency goals
Identify stressors	Identify Stressors	Refine/expand stressors to be evaluated	Identify regional/national priority stressors to evaluate
Conceptual models	Develop conceptual models (surface and ground water, aquatic ecology, surface disturbance)	Validate/refine existing models Develop new models Use models to develop adaptive management predictions	Update models with data from monitoring network Compare and evaluate models
Select indicators	Prioritize indicators	Use predictions to select appropriate indicators ID priority research and monitoring needs to validate models or address critical monitoring needs	Identify common priority regional/national indicators ID priority monitoring needs
Sampling design and analysis	ID and evaluate data available Assessment scales of analysis Assessment design/analysis Priority/focal monitoring sampling design	Evaluate new data sources Targeted adaptive management and research design Priority retrospective and baseline monitoring design	Develop standards for monitoring regional and national priority indicators Develop database management and analysis protocols Coordinate research, baseline, prospective, retrospective monitoring design
Response criteria	Establish condition classes for selected indicators	Refine/establish condition classes for selected indicators	Establish condition classes for selected regional/national indicators

Link to decision making	Develop management targets and management framework	Evaluate and refine management targets and management strategies	Evaluate and refine management targets and management strategies at regional and national levels

Implementation of the Regional Framework

A three-phased approach to implementation would be used to take advantage of existing information and to provide design flexibility as new information is obtained. These phases are:

Phase I: Integrate Existing Data and Models

Phase II: Begin Monitoring Programs and Expand Predictive Capabilities

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

Components of the three-phased monitoring program related to the disciplines surface water, stream biology, ground water, surface disturbance, and modeling are outlined in the following sections. Each section has been developed to illustrate the implementation of the three-phased approach for each of the disciplines. While activities for each discipline can stand alone there is a critical integration component that blends results into a more comprehensive understanding the effects of energy development on water resources. Integration between disciplines can be as simple as developing new relations between independent (resource) and explanatory variables (stressors) to robust modeling efforts that lead to decision-support systems. These integration steps will be driven by the needs of land managers to answer questions about the effects of energy development on water resources. The Regional Framework presented in this report can only be effectively implemented by BLM in coordination with other agencies, governments, and industry. State regulatory processes can be supported by the regional framework. Instream water-quality standards, ground water-quality standards, and administration of water rights are a few examples of the types of state functions that would benefit from the information provided by the regional framework. Groups like the Powder River Basin Coal Bed Natural Gas Interagency Working Group (http://www.wy.blm.gov/prbgroup/links.htm) provide an example of the opportunities for collaboration between local, state, tribal, and federal entities and to identify and direct integration efforts. Finally, the regional framework includes reference to a "common data repository". It is anticipated that water-resources information will reside in a number of disparate formats and platforms. Over time access to all or most water-resources data will facilitate data accesses and analysis. Describing the development of a common data repository is not outlined in the Regional Monitoring Framework information on this process can be found in Brown and Wynn (2004 and 2005)

Surface-Water Resource Monitoring Related to Energy Development

The National Research Council (NRC), in its publication "Hydrologic Sciences: Taking Stock and Looking Ahead," emphasized that the study of hydrologic processes at all scales including regional–scale hydrologic analysis and hydrochemical processes is needed to understand anthropogenic effects on hydrology (NRC, 1998). Design streamflow and water quality sampling networks should reflect the integration of landscape conditions found in a watershed. Existing conditions (baseline conditions) need to be characterized for a long enough duration to define the existing variability (Yapo and others, 1996) and should occur prior to expected development in a watershed. Turk and others (1986) describe methods for hydrologic monitoring of impacts from surface mining in the west central United States. The report describes processes and characteristics that control surface and subsurface hydraulics, as well as the water quality, of typical hydrologic systems in the central-western United States. Turk also discusses approaches to hydrologic monitoring network design. Lumb (1982) describes techniques that assess probable cumulative impacts from surface mining. Impacts are quantified using a hydrologic model and develops profiles showing percentage change in hydrologic characteristics (streamflow and water quality) versus distance downstream of a mining site. Tasker (1986) uses regional regression analysis that describes a method for collection of regional streamflow information for various levels of network operation. Moss and Tasker (1991) compare techniques to maximize regional streamflow information within a limited budget and time horizon. A method for optimizing the selection of river sampling sites is presented by Dixon and others (1991) for systems intended for trend detection, measurements in support of regulation and for estimation of pollutant loadings. These methods can be used to evaluate existing networks and recommend the number of streamflow-gaging stations needed to meet monitoring objectives. Another method described by Lanfear (2005) uses an incremental-stepping procedure to determine an optimum number of stations needed to meet program goals. The stepping procedure includes Basic Feasible Incremental Solutions (BFIS) where each BFIS represents a goal for a streamgaging network. A BFIS can be related to development of streamflow information for water rights (compacts and decrees), water budgets, regionalization of streamflow characteristics, and location of water-quality stations. Gilliom (1995) discusses the difficulties in sampling network design that produce consistent descriptions on a national scale (multiple regions) that are persistent over time and still assess conditions that are short lived or unevenly distributed in a region. The USGS National Water Quality Assessment (NAWQA) describes status and trends water resources and links water-resource conditions to natural and human factors. The design is based on balancing assessment requirements of individual hydrologic systems (regions) while incorporating a consistent design that incorporates a multiscale interdisciplinary approach.

One example of how a framework for regional surface-water monitoring could be implemented is the Upper Colorado River regional study of water quality by USGS (Spahr and others, 1996 & 2000). Sampling sites were selected after a retrospective analysis of existing hydrologic information (Apodaca and others, 1996). The surface-water assessment component of the framework was implemented using a stratified network of basic fixed surface-water sites. These sites represent a stratification where areas are subdivided on the basis of similarities in major natural and/or human factors such as topography, geology, climate, and land use (Sun and Johnston, 1994; Gilliom and others, 1995). The sampling sites include integrator and indicator basic fixed sites. Integrator sites are usually at the outflow of a watershed and represent the streamflow and water-quality characteristics at effected by many land uses and impacts on water resources. Indicator basic fixed sites represent selected land uses and water-quality impacts. These sites represent environmental gradients (geologic, topographic, intensity and type of development) in a region. Special types of indicator sites are reference sites that represent smaller watersheds that are minimally impacted by development. Probabilistic sample design methods can be incorporated in the selection of integrator sampling sites to ensure statistically valid spatial coverage in a region (Hirsch and Hamilton, 2006).

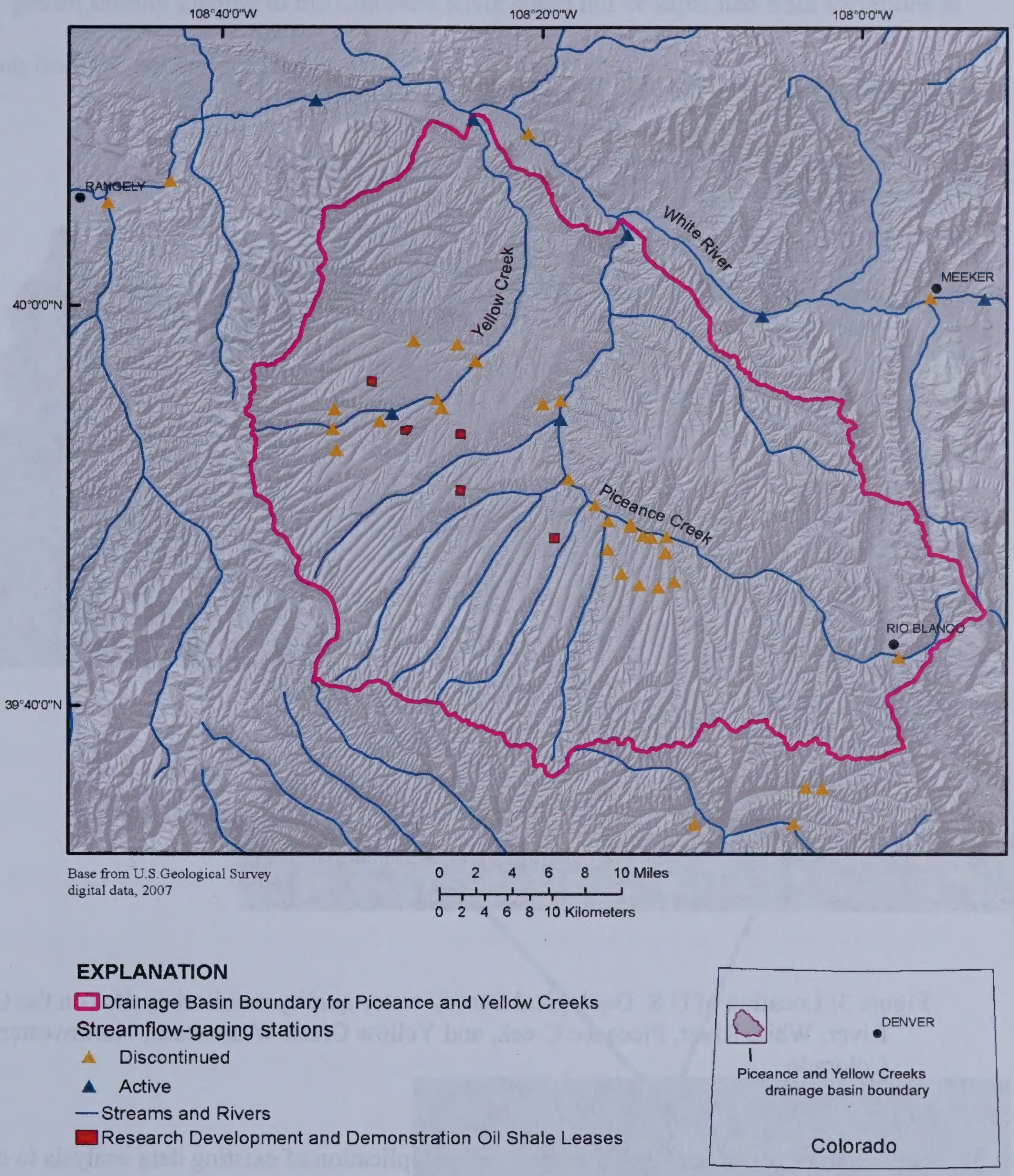
Determining how development effects on water quantity and quality will propagate in a watershed requires knowledge seasonal variability of streamflow and water-quality constituents and trends associated with natural variability and the effects from development. However, monitoring data generally provide evidence of past and present human effects on water resources, but they cannot forecast future cumulative effects (temporal up-scaling). Watershed modeling can be used to overlay expected land-use changes to forecast anticipated effects of development on watershed processes. To help with model selection, application, and analysis, a set of modular modeling tools, termed the Modular Modeling System (MMS) is being developed by the NRP Precipitation-Runoff Modeling Project (Leavesly and others, 1998). The approach being applied in developing MMS is to enable a user to selectively couple the most appropriate process algorithms from applicable models to create an "optimal" model for the desired application. Where existing algorithms are not appropriate, new algorithms can be developed and easily added to the system. This modular approach to model development and application provides a flexible method for identifying the most appropriate modeling approaches given a specific set of user needs and constraints. Watershed models can be useful forecasting tools because they can synthesize the most current conceptual models with the best available hydrologic data in a quantitative fashion to provide understanding of cause and effect in a regional hydrologic system. Characterization of watershed process at multiple scales using numerical models also aids in spatial up-scaling of monitoring data by providing regional context to local watersheds in which monitoring networks may be located. A combination of data collected at integrator and index monitoring sites with data integration using watershed modeling would provide the framework for regional monitoring of surface-water resources in the White River and Glenwood Springs Resource Areas of the Piceance Basin.

Phase I: Integrate Existing Data and Models

The primary objectives of Phase I are (1) develop a preliminary understanding of the regional surface-water hydrologic system through the use of models and existing information, (2) identify data gaps in the understanding, (3) identify indicators of energy impacts on water resources, and (4) design new monitoring programs to fill data gaps and begin trend monitoring for indicators.

The first step in meeting these objectives would be to map the distribution of hydrologic landscapes (stratify the region) using GIS databases for features like topography, geology, soils, climate, vegetation, hydrologic features, lease areas, gas-well locations, and evaporation pond locations. The hydrologic landscape map would provide regional context for evaluating other existing data such as streamflow and water quality. This analysis forms the basis for developing preliminary conceptual and numerical models of water movement in the regional hydrologic system. The hydrologic landscape map and numerical watershed models will be the primary tools for evaluating (up-scaling) data from nested monitoring networks in the regional context (Phase III).

Examples of identifying data gaps using historic information include the evaluation of the historic and active streamflow-gaging and water-quality sampling network in the White River watershed related to proposed energy development activities (figs. 2 and 3). Network analysis tools (Lanfear, 2005) would be used to determine what level of monitoring is needed.


108°40'0"W
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108°0'0"W
40°0'0"N
39°40'0"N
RANGELY
MEEKER
RIO BLANCO
White River
Yellow Creek
Piceance Creek
Base from U.S.Geological Survey digital data, 2007
0 2 4 6 8 10 Miles
0 2 4 6 8 10 Kilometers
EXPLANATION
Drainage Basin Boundary for Piceance and Yellow Creeks
Streamflow-gaging stations
Discontinued
Active
Streams and Rivers
Research Development and Demonstration Oil Shale Leases
DENVER
Piceance and Yellow Creeks drainage basin boundary
Colorado

Figure 2: Location of research development and demonstration oil shale lease areas and active and discontinued surface-water sites in the White River, Piceance Creek, and Yellow Creek Watersheds, Northwestern Colorado.

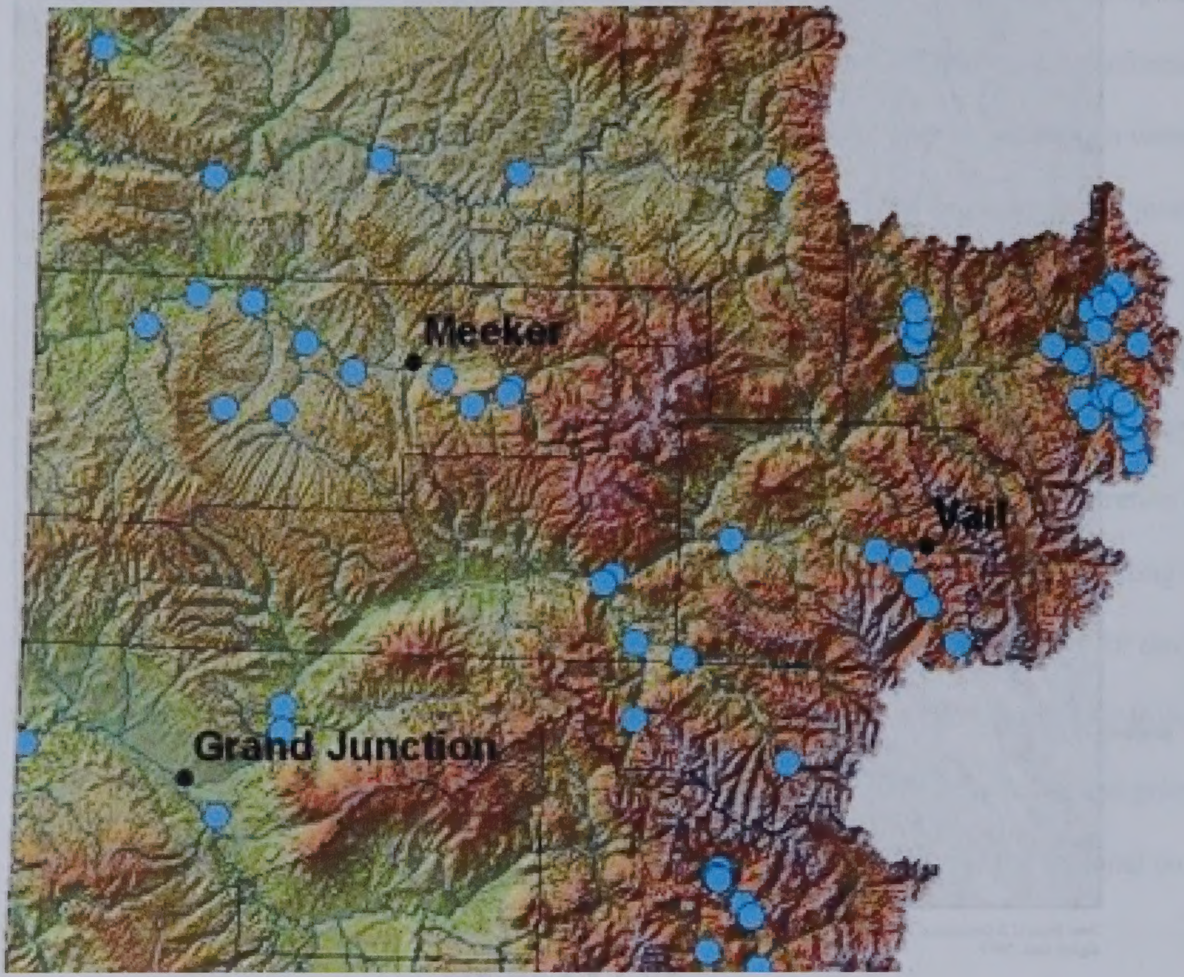
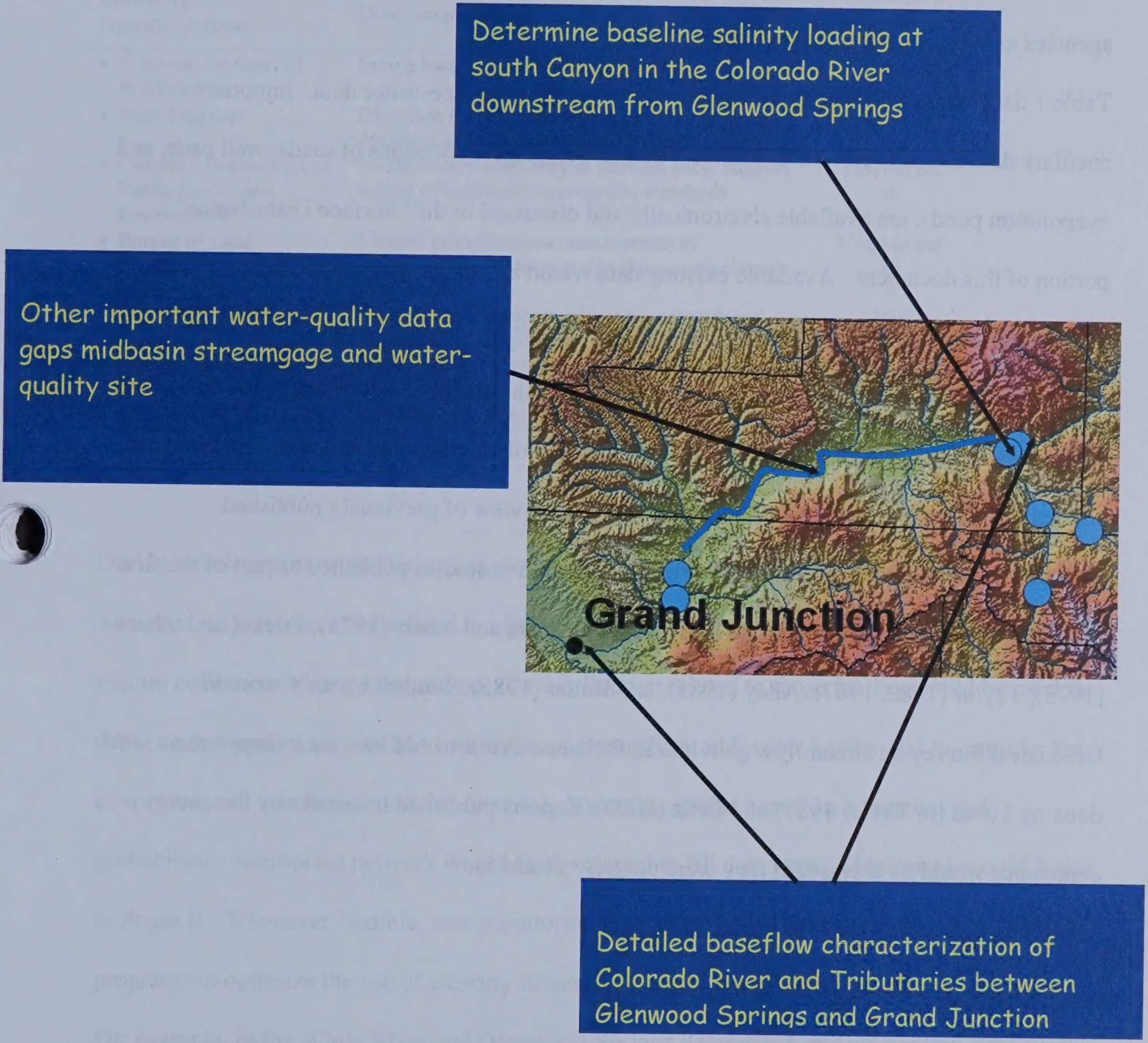


Figure 3: Location of U.S. Geological Survey water-quality monitoring sites on the Colorado River, White River, Piceance Creek, and Yellow Creek Watersheds, Northwestern Colorado

Another example of identifying data gaps is the application of existing data analysis to current monitoring networks. Leib (in press) identified a significant data gap along the Colorado River between the cities of Glenwood Springs and Grand Junction. Examination of trends in salinity concentrations and loads was unable to account for variation in salinity originating from a Glenwood Hot Springs. Without additional data collection the effects of extensive development of natural gas on salinity loading to the Colorado River could not be separated from variations in salt loading from the hot springs (figure 4).



Determine baseline salinity loading at south Canyon in the Colorado River downstream from Glenwood Springs

Other important water-quality data gaps midbasin streamgage and water-quality site

Detailed baseflow characterization of Colorado River and Tributaries between Glenwood Springs and Grand Junction

Figure 4: Potential data gaps on the Colorado River Northwestern Colorado

The types and sources of data for surface-water quantity and quality in the White River and Glenwood Springs Resource Areas are extensive (Taylor, 1987; Tobin, 1993; Ortiz, 2000). Data have been collected, and in some cases analyzed, by local, state, and federal governmental agencies as well as by the energy industry.

Table 1 lists examples of the types and sources of existing surface-water data. Important ancillary data that are relevant to surface-water issues, such as locations of roads, well pads, and evaporation ponds, are available electronically and discussed in the "Surface Disturbance" portion of this document. Available existing data would be gathered, assessed for their accuracy, and entered into a common data repository prior to analysis. In addition to gathering and analyzing existing data, it would be important to assess the current level of understanding of the surface-water flow system to both expedite the analysis of existing data and to guide new data collection. This assessment would require a thorough review of previously published interpretive ground-water studies. Some of the interpretive studies published as part of the first oil-shale development effort include the reports by Coffin and others (1971), Frickel and others (1975), Taylor (1982, 1987), Alley (1983), and Butler (1985). Studies by the Colorado Geological Survey on streamflow gain loss in Piceance Creek would be used to supplement work done by Tobin (in Taylor 1987) and Ortiz (2000). Reports published internally by the energy companies would be assessed if they were publicly available.

Table 1. Examples of the types and sources of surface-water data available for the White River and Glenwood Spring Resource Areas. This list is not comprehensive.

Collecting Agency/Company	Description of data	Available in electronic format
• Colorado Division of Wildlife	Spring locations, flow, water-quality	Yes, but not all
• State Engineer	Diversion records, selected streamflow gaging, distribution and administration of water rights.	Yes, but not all
• Colorado Department of Public Health and Environment	Surface-water chemistry at selected sites. Support setting of instream water-quality standards	Yes, but not all
• Bureau of Land Management	Limited miscellaneous measurement of streamfllow and water-quality data, some climatic information.	Yes, but not all
• U.S. Geological Survey	Current and historic streamgaging network and water-quality sampling sites chemistry	Yes
• Encana Oil and Gas (USA), Inc.	Water quality data provided by Kim	Yes, but not all
• Other energy companies	Compliance monitoring	Unknown

During development of the hydrologic landscape map and the conceptual and numerical models, data gaps may be identified related to climate, geology, streamflow, and water chemistry that require collection of new information. Data collection related to those factors would be used to refine understanding of baseline conditions of streamflow and water quality and to improve the conceptual and watershed models. New monitoring programs based on a targeted and probabilistic monitoring network would be developed to fill data gaps. Monitoring would begin in Phase II. Whenever feasible, new monitoring programs should be coordinated with existing programs to optimize the use of existing streamflow gages, sampling programs, and equipment. For example, in the White River and Glenwood Springs Resource Areas an existing streamflow gaging and water-quality sampling network has been operated in cooperation with local, state, and federal agencies on the Colorado River and the White River and in the Piceance Creek and Yellow Creek watersheds.

A primary product of the analysis of existing information and development of preliminary models is a list of indicators of energy impacts on water quantity and quality. The indicators would be evaluated relative to land health standards, ambient instream water-quality standards, and other relevant health/management standards and goals. The stratified nested network of streamflow gages and water-quality sampling sites would be used to begin trend monitoring for those indicators in Phase II. Possible indicators could include streamflow, specific conductance, water-temperature, sediment concentration, and selected trace elements and organic water-quality parameters. As part of the effort to define indicators of energy impacts, an integrated team of managers, industry representatives, and scientists would periodically review existing data and modeling results to keep parties informed and focused on management objectives.

Phase I tasks, time estimates, and personnel requirements are listed in Table 2. Table 3 lists the expected products from Phase I.

Table 2. Tasks associated with Phase I and approximate time and personnel requirements for completing tasks.

Task	Time requirement	Personnel requirements
• Find relevant existing data, assess accuracy, and add to common data repository	12 months	Junior hydrologist, GIS specialist, students
• Make Hydrologic Landscape map	3 months	Senior hydrologist, GIS specialist
• Analyze streamflow and water-quality data in context of hydrologic landscapes	6 months	Hydrologists (senior and junior), GIS specialist
• Create preliminary conceptual models to illustrate and explain factors controlling the streamflow and instream water quality	3 months	Hydrologists (senior and junior)
• Create preliminary watershed model as a tool to forecast regional effects of energy development on water resources	18 months	Hydrologists (senior and junior), GIS specialist, student
• Identify data gaps. Coordinate with existing monitoring programs and develop new monitoring programs to fill data gaps. Monitoring would begin in Phase II.	9 months	Hydrologists (senior and junior), GIS specialist
• Use data, retrospective analysis, and watershed models to identify surface-water quantity and quality indicators of energy impacts. Evaluate	6 months	Hydrologists (senior and junior)

indicators relative to land health standards, ambient surface-water quality standards, and other relevant health/management goals. Establish preliminary baseline for indicators.		
• Develop trend-monitoring program for indicators. Monitoring would begin in Phase II.	3 months	Hydrologists (senior and junior)
• Review of existing data and modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives	At least twice during Phase I	Senior hydrologist
TOTAL TIME REQUIRED FOR PHASE I	**18 months**	--

Table 3. Expected products from Phase I.

PRODUCTS

- Water-resources information entered into a common data repository.
- Hydrologic Landscape map.
- Preliminary conceptual model of streamflow-water systems and resultant water quality.
- Preliminary watershed models
- List of indicators of energy impacts on surface-water resources.
- Monitoring plans to fill data gaps and initiate trend monitoring for indicators.
- Interpretive report evaluating baseline conditions of streamflow and water quality.
- Interpretive report evaluating indicators relative to land health standards, ambient instream water-quality standards, and other relevant health/management standards and goals.

Phase II: Begin Monitoring and Expand Predictive Capabilities

The primary objectives of Phase II are (1) improve understanding of baseline conditions for indicators, (2) implement trend monitoring for indicators, and (3) expand the predictive capabilities of tools (primarily Hydrologic Landscape map and models) that would be used for spatial and temporal up-scaling of monitoring results in Phase III. Phase II is considered to be an important intermediate step between evaluation of existing data (Phase I) and fully implementing a monitoring program (Phase III) because it would expand understanding of baseline conditions for indicators prior to fully implemented trend monitoring for indicators. Tools for up-scaling monitoring data would be tested during Phase II. Feedback from this analysis would be used to update the list of indicators and revise monitoring plans and modeling tools.

An important task near the end of Phase II is an assessment of the monitoring network in terms of its adequacy with respect to areal coverage and sampling frequency. A detailed description of the tools and methods used in that analysis is beyond the scope of this document, however, several examples of their application to other surface-water monitoring networks are available in the literature for reference (Moss and Tasker, 1991 and Lanfear , 2005). This task is necessary to optimize the final monitoring network implemented in Phase III. This analysis could result in the expansion or contraction of streamflow gaging stations and water-quality sampling sites.

Phase II tasks, time estimates, and personnel requirements are listed in Table 4. Table 5 lists the expected products from Phase II. As in Phase I, an integrated team of managers, industry representatives, and scientists would periodically review data and modeling results to keep parties informed and focused on management objectives.

Table 4. Tasks associated with Phase II and approximate time and personnel requirements for completing tasks. The time requirements assume that some, but not all, data collected by the energy industry are available for analysis.

Task	Time requirement	Personnel requirements
• Implement nested monitoring program to fill data gaps and begin measuring trends in indicators	18 months	Hydrologic technicians, Junior hydrologist, GIS specialist
• Revise Hydrologic Landscapes map	3 months	Senior hydrologist, GIS specialist
• Expand understanding of baseline conditions for indicators	6 months	Hydrologists (senior and junior), GIS specialist
• Revise conceptual and watershed models	18 months	Hydrologists (senior and junior)
• Update list of indicators	3 months	Hydrologists (senior and junior), GIS specialist, student
• Evaluate monitoring programs and revise as needed	3 months	Hydrologists (senior and junior), GIS specialist

• Review of existing data and modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives	At least twice during Phase II	Senior hydrologist
TOTAL TIME REQUIRED FOR PHASE II	**18 months**	--

Table 5. List of Phase II Products.

PRODUCTS
• Updated Hydrologic Landscapes map.
• Revised conceptual model of ground-water movement and quality.
• Revised watershed models
• Updated list of indicators of energy impacts on surface-water resources.
• Revised monitoring plan for filling data gaps and measuring indicators.
• Interpretive report evaluating indicators relative to land health standards, ambient instream water-quality standards, and other relevant health/management standards and goals.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

The stratified nested monitoring program is fully implemented in Phase III to (1) measure trends for indicators of energy impacts on streamflow and water quality (surface-water assessment) and (2) refine predictive tools. Monitoring results are interpreted in the regional context provided by the Hydrologic Landscape map and models so that cumulative effects of energy development on regional water resources can be assessed. One outcome of this assessment could be identification of water resources that are impaired by energy development. In that case, corrective action may be required, followed by performance monitoring.

Phase III tasks and personnel requirements are listed in Table 6. Table 7 lists the expected products from Phase III. The timeline for Phase III would depend on several factors that cannot be determined at this time, including extent and duration of energy development and the magnitude of energy impacts on the regional hydrologic system.

As in Phases I and II, an integrated team of managers, industry representatives, and scientists would periodically review data and modeling results to keep parties informed and focused on management objectives.

Table 6. Tasks associated with Phase III and approximate time and personnel requirements for completing tasks. The time requirements assume that some, but not all, data collected by the energy industry are available for analysis.

Task	Time requirement	Personnel requirements
• Fully implement revised monitoring program and continue trend monitoring for indicators	To be determined	Hydrologic technicians, Junior hydrologist, GIS specialist
• Forecast (spatial and temporal up-scaling) regional effects of energy development on water resources	To be determined	Senior hydrologist, GIS specialist
• Evaluate indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals	To be determined	Hydrologists (senior and junior), GIS specialist
• Identify corrective action needs	To be determined	Hydrologists (senior and junior)
• Integrated team of managers, industry representatives, and scientists develop and implement corrective actions (Best Management Practices, BMPs)	To be determined	Hydrologists (senior and junior), GIS specialist, student
• Performance monitoring of BMPs	To be determined	Hydrologic technicians, Junior hydrologist, GIS specialist
TOTAL TIME REQUIRED FOR PHASE III	To be determined	--

Table 7. List of Phase III Products.

PRODUCTS
• Tools for evaluating monitoring results in regional context.
• Monitoring program that integrates surface-water assessment (baseline and trends) and surface-water science (understanding).
• Interpretive reports evaluating indicators relative to land health standards, ambient instream water-quality standards, and other relevant health/management goals.
• Interpretive reports explaining monitoring results in framework of controlling natural and anthropogenic factors.

Stream Biology Resource Monitoring Related to Energy Development

BLM is obligated to uphold the protection of the integrity of surface waters under its management as mandated by EPA through the states under the Clean Water Act Amendments to the United States' Pollution Control Act of 1972. The most direct and effective measure of the integrity of streams is the status of its living systems, as they have evolved under specific environmental conditions for millennia (Karr and Chu, 1999). These living systems respond in somewhat predictable ways to human disturbances such as large-scale landscape changes related to energy development. Algae, fish and invertebrate assemblages are useful indicators of the integrity and biological status of streams but all assemblages may not be appropriate in every region. The Colorado Department of Public Health and Environment (CDPHE) is currently developing state-wide analytical tools and guidelines for determining biological status of streams based on invertebrates that will be in place by 2010 (http://www.cwqf.org/Workgroups/Content/Aquatic_Life/Documents/Roadmap%20Revision.pdf). These tools will be used in a state-wide stream bioassessment program (Chris Theel, 2006, oral comm., Colorado Department of Public Health and Environment, Monitoring Unit, Denver, Colorado). Drafts of the analytical tools are currently available (http://www.cwqf.org/Workgroups/Content/Aquatic_Life/Documents/Development%20of%20Biological%20Assessment%20Tools.pdf) and can be used as a guideline to develop a regional approach to stream biology resource monitoring as related to energy development by the BLM in Colorado.

Numerous methods that summarize biological response to disturbance have been used in stream bioassessments (see Metcalfe, 1989, Johnson et al. 1993). Many of these methods use various aspects of community structure and composition. Two commonly used indicators include multimetric indices (e.g. Index of Biotic Integrity, IBI) and multivariate predictive type models (e.g. observed to expected ratios, O/E) (Karr and others, 1986, Wright, 1995, Barbour and others, 1999). Both methods rely on comparisons between calculated IBI or O/E values from sites being evaluated and expected values based on observations from a series of comparable reference sites. Regardless which indicator is used, correctly and narrowly defining reference condition is imperative to a meaningful assessment. Stoddard and others (2006) clearly discuss the concept of setting expectations of reference condition. Often, reference condition is more appropriately defined as the best available condition where biological communities are the closest to natural as possible for a particular region.

As part of developing IBI and O/E predictive models for state assessment tools, the CDPHE is currently defining reference condition for Xeric, Southern Rocky Mountain and Western High Plains Ecoregions in Colorado. The Xeric and Western High Plains bioregions in Colorado are under-sampled and in need of a better understanding of reference condition (Chris Theel, 2006, oral comm., Colorado Department of Public Health and environment, Monitoring Unit, Denver, Colorado). Integrating a BLM regional biomonitoring program with CDPHE will enhance both agencies bioassessment efforts in the Xeric bioregion of Colorado.

Multimetric Indexes

Multimetric indexes such as the IBI are used as indicators of ecosystem wellbeing that incorporate multiple biological community characteristics to measure overall community response to environmental change (Karr et al. 1986, Barbour et al. 1995). This type of indicator was first developed for fish (Karr 1981, Karr 1991) but has since been widely applied to benthic invertebrates, periphyton, and birds (Bahls 1993, Barbour and others, 1999, Bryce and others

2002). Metrics are chosen that best discriminate between comparable reference and disturbed sites across a region (Barbour and others, 1999). Example metrics for benthic macroinvertebrate communities might include total taxa richness, tolerant taxa abundance, proportion of scraper taxa, and mayfly abundance among others. In general, metric values are calculated and rescaled to values calculated from reference sites. These rescaled metric values are then summed into a single measure that represents overall biological status of a site often defined as condition, health, or integrity. Bioassessment tools further incorporate threshold multimetric index values that define biological status into categories (e.g. "good", "fair", or "poor"). The multimetric approach has been widely applied to bioassessment programs in the United States and other countries and is currently one of the bioassessment tools being developed by CDPHE that could be used by BLM to assess the influence of energy development on stream ecosystems.

Multivariate Predictive Models

Researchers in the United Kingdom developed the River Invertebrate Prediction and Classification System (RIVPACS) approach, a multivariate predictive model, to assess site condition based on the taxonomic completeness of a sample (i.e. observed, O) as compared to a regional reference condition (i.e. expected, E) measured as the ratio of O/E (Moss and others, 1987, Wright, 2000). Values can range from 1 (reference condition) to zero (completely degraded). In general, the creation of the RIVPACS type model to calculate O/E consists of two steps: (1) classification of reference sites based on their biologically similarity and (2) development of a model to predict class membership of new sites being evaluated. Reference site classification results in defining groups of sites that are biologically similar to one another. The biota from each distinct group of sites is then used for defining the regional reference condition

(E) for each distinct set of reference sites. Once expected condition is defined for different reference site types, a discriminant function model is constructed of environmental variables that assign new sites being evaluated with their appropriate reference site for comparison. Discriminant function models (DFM) relate group membership to the variability associated with a set of predictor variables. Typical predictor variables used in these DFM are not influenced by humans and might include measures of latitude, longitude, basin size, climate, and geology. The DFM model estimates the probability that a new site (observation) belongs to a particular group of reference sites. These DFM probabilities are used to weight taxa probabilities of detection by weighting the taxa frequencies of occurrence in each group of reference sites. For further detail on building multivariate predictive models to calculate O/E see Hawkins and Carlisle (2001). This approach has been used in Australia (Marchant et al. 2002), Canada (Reynoldson and others, 2001), New Zealand (Joy and Death, 2003), Sweden (Johnson 2003), and the United States (Hawkins and others, 2000). A RIVPAC type model is currently being developed for Colorado by CDPHE in cooperation with the Western Center for Monitoring and Assessment of Freshwater Ecosystems (Utah State University, Logan Utah) as one of the bioassessment tools being developed that could be adopted by BLM to assess the influence of energy development on stream ecosystems.

Phase I: Integrate Existing Data and Assessment Tools

The primary objectives of Phase I are to 1) develop a preliminary understanding of the status of biological systems in the area proposed for energy development, 2) identify data gaps and 3) design efforts to fill data gaps and deficiencies.

The first steps in meeting phase I objectives 1 and 2 is to gather and map existing bioassessment data on the biological status of streams within the region proposed for development. Very little benthic macroinvertebrate work is reported in the literature from the area (Covay and others, 1985, Taylor 1982, 1987). There are likely other sources that have been produced by local consultants. The utility of the available data is likely limited in the area proposed for energy exploration and development in Colorado. The most comparable benthic data in the region will likely be available from the CDPHE and possibly from the Western Center for Monitoring and Assessment of Freshwater Ecosystems (Utah State University, Logan, Utah). Nonetheless, it will be important to address if existing data are available that can be applied to bioassessment tools to enhance the current understanding of the status of biological integrity of stream systems in the area proposed for energy development. This preliminary exercise will allow BLM to evaluate if land health standards, State Aquatic Life Use Guidelines, and other relevant health/management goals are currently being achieved or even if reasonable assessments can be made at this time. Additionally, this exercise will likely enhance the premature state of current CDPHE's bioassessment tools while identifying the data gaps necessary to make stream assessments. Furthermore, biological data should be compiled on federally or state listed fish species in the area or downstream that might be influenced by energy development activities. These species include but are not limited to Colorado River cutthroat trout (*Oncorhynchus clarki virginalis*), mountain sucker (*Catostomus playtrhynchus*), razorback sucker (*Xyrauchen texanus*) bonytail chub (*Gila elegans*), roundtail chub (*Gila robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*). Other native unlisted species that might be influenced by energy development activities include modeled sculpin (*Cottus bairdi*), flannelmouth sucker (*Catostomus latipennis*), and bluehead sucker (*Catostomus discobolus*).

Once data gaps are understood, it will be necessary to design an appropriate data collection program to eliminate any data deficiencies. This major task should be coordinated with existing bioassessment programs occurring in the region, mainly with those efforts being undertaken by CDPHE and their supporting agencies. This effort will require BLM to clearly define monitoring objectives, as well as definitive management goals and questions. A major part of this effort will likely be directed towards gaining a better understanding of reference condition (Stoddard and others, 2006) in the area proposed for energy exploration. Data collection efforts addressing deficiencies will begin in Phase II.

The primary products in Phase I includes the identification of data gaps and a well-designed monitoring program integrated with CDPHE's current bioassessment program. As part of this process, detailed conceptual models will be developed that describe how stream biology is expected to respond to energy exploration and development. Additionally, a preliminary assessment of the regional status of streams will be evaluated and presented to BLM managers, industry representatives, and other agency scientists to keep parties informed.

Table 8. Phase I tasks and products for stream biology resource monitoring.
[NOTE TO REVIEWER: DETAILS ON STAFFING NEEDS WILL BE INCLUDED IN FINAL]

TASKS

- Find relevant existing data and add to common data repository.
- Evaluate the status of sites from existing data using data analysis tools being developed by the Colorado Department of Public Health and Environment or by the Western Center for Monitoring and Assessment of Freshwater Ecosystems. It may be necessary to enhance current bioassessment tools if new data are available.
- Evaluate indicators relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals.
- Identify data gaps.
- Coordinate with existing monitoring programs to develop new monitoring programs to fill data gaps to better address the above tasks.
- Clearly define objectives for the monitoring program.
- Create preliminary conceptual models based on the literature and existing data to illustrate and explain potential factors controlling the biological status of streams proposed for energy exploration and development.
- Review results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.

PRODUCTS

- Map of the regional distribution of stream assessments already made and additional data that could be evaluated using CDPHE bioassessment tools.
- Preliminary conceptual model of how biological systems might respond to energy exploration and development.
- Plans for an integrated monitoring program designed to fill data gaps and address clearly defined objectives.
- Interpretive report evaluating what is known about the current biological status of streams relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals.

Phase II: Begin Monitoring and Expand Predictive Capabilities

The primary objectives of Phase II are to 1) fill data gaps identified in Phase I, 2) design and implement research to test conceptual models designed in Phase I, and (3) improve assessment tools by integrating new data.

Phase II is an important intermediate step between the evaluation of existing data (Phase I) and fully implementing a monitoring program (Phase III) because it refines our understanding of reference conditions prior to fully implementing the regional monitoring program. Testing the conceptual models will further our understanding of the influence of energy exploration and development on stream ecosystems. Once the assessment tools are improved and reference conditions are defined any site in the region can be evaluated for compliance of BLM Land Health Standards, CDPHE Aquatic Life Use Criteria, and other management goals.

The primary products in Phase II include refined bioassessment tools as well as a better understanding of the status of streams in the area being explored. As part of this process, conceptual models will be refined and updated with supporting data to help better understand how these systems will respond to energy development and exploration. From this effort, the ability to predict how these systems will respond to energy development and exploration will be enhanced.

Table 9. Phase II tasks and products for stream biology resource monitoring.

TASKS

- Fill data gaps by collecting new data based on the data gaps identified in Phase I.
- Design and implement research to test the preliminary conceptual models designed in Phase I.
- Refine conceptual models and assessment tools by integrating the newly collected data.

PRODUCTS

- Updated common data repository.
- Refined conceptual models and assessment tools.
- Refined assessment of Land Health Standards.
- Interpretive report evaluating the biological status of streams as related to energy exploration and development.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

The biomonitoring program based on clearly stated objectives that addresses discrete management questions and goals is fully implemented in Phase III. The major outcome of this effort will be the identification of water resources that are impaired by energy development so that corrective action can be taken, followed by continued monitoring.

Development of a specific monitoring program based on clearly stated objectives for the White River and Glenwood Springs Resource Areas is beyond the scope of this document. However, the effectiveness of any bioassessment program is anchored in a well developed understanding of regional reference condition, which will require the collection of additional data. A strategically designed monitoring network will allow BLM to access any site in the sampling frame as well as determine changes in biological condition over time, and predict future changes in areas currently undeveloped.

Table 10. List of Phase III Tasks and Products.

TASKS

- Fully implement revised monitoring program and continue trend monitoring.
- Determine effects of energy development on stream systems at any scale within the sampling frame.
- Evaluate indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals.
- Identify corrective action where needed.
- Integrated team of managers, industry representatives, and scientists develop and implement corrective actions where necessary (Best Management Practices, BMPs).
- Performance monitoring of BMPs.

PRODUCTS

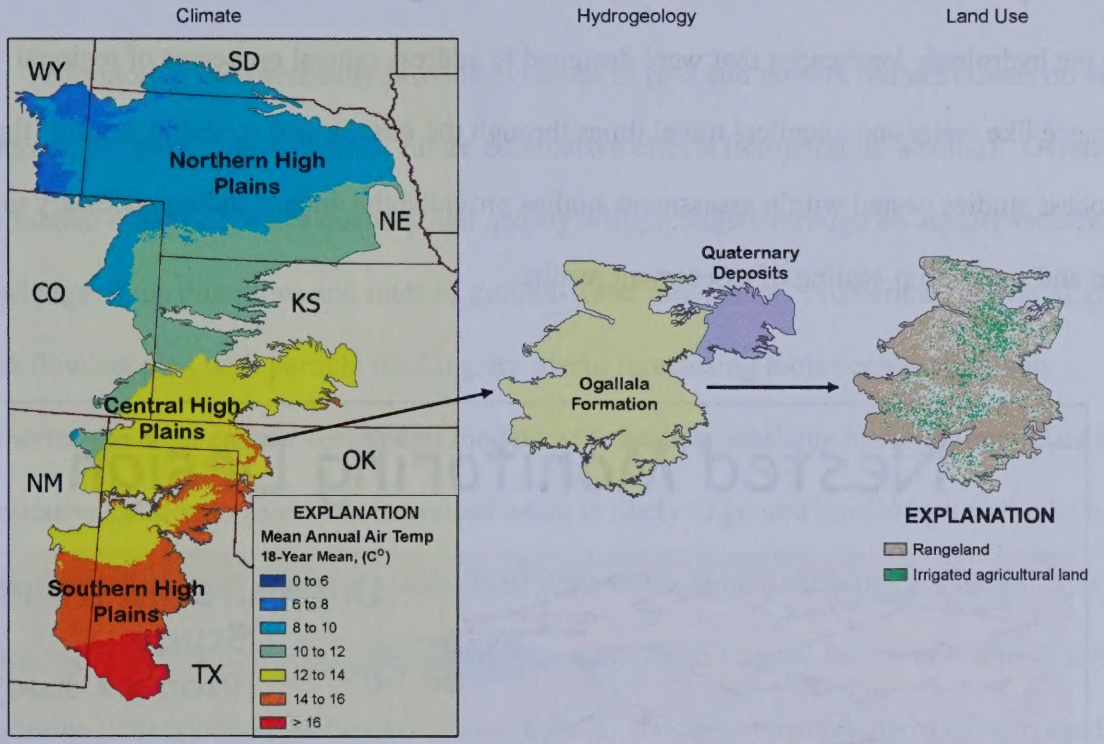
- Tools for evaluating monitoring results in regional context.
- Monitoring program that integrates ground-water assessment (observation) and ground-water science (understanding).
- Interpretive reports evaluating indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals.
- Interpretive report evaluating the current biological status of streams relative to land health standards, State Aquatic Life Guidelines, and other relevant health/management goals

Ground-Water Resource Monitoring Related to Energy Development

The National Research Council (NRC), in its publication "Investigating Groundwater Systems on Regional and National Scales," concluded that regional ground-water monitoring studies should have two distinct but complimentary components: ground-water assessment and ground-water science (NRC, 2000). The assessment component includes evaluation of baseline conditions and trends and the science component includes the study of critical processes of regional importance like recharge, ground-water flow directions and rates, and discharge that help to explain baseline conditions and trends. As stated in the NRC report, "Assessment and science are not independent. Regional assessments quantify and project the impacts from man-made and natural stressors of hydrogeologic systems. These impacts motivate policy and decision-making dynamics and also drive the need for better regional ground-water science…Improved process based ground-water science on regional scales, in turn, supports improved management and policy-making on regional scales. Thus, regional ground-water assessments and regional process-based science form the foundation supporting the synthesis of groundwater investigations on regional and national scales."

One example of how the NRC framework for regional monitoring could be implemented is the High Plains Regional Ground-Water Study of the USGS (Bruce and others, 2006; http://co.water.usgs.gov/nawqa/hpgw/index.html). The ground-water assessment component of the framework was implemented using a stratified network of monitoring wells. Stratification is the process by which large areas are subdivided on the basis of similarities in major natural and/or human factors such as topography, geology, climate, and land use (Sun and Johnston, 1994; Gilliom and others, 1995) (fig. 5).

Example of a Stratification Scheme Used in the High Plains Regional Ground-Water Study


Climate
Hydrogeology
Land Use
WY
SD
Northern High Plains
NE
CO
KS
Central High Plains
NM
OK
Southern High Plains
TX
EXPLANATION
Mean Annual Air Temp 18-Year Mean, (C°)
0 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
> 16
Quaternary Deposits
Ogallala Formation
EXPLANATION
Rangeland
Irrigated agricultural land

Stratification
Process by which large areas are subdivided on the basis of similarities in major natural and/or human factors such as topography, geology, climate, and land use.

High Plains Example
Stratification based On climate, hydrogeology, And land use.

Hydrologic Landscapes or sub-areas
Hydrogeology within a sub-area is expected to be relatively uniform from the regional perspective; therefore, data from monitoring networks in the sub-area presumably can be extrapolated to unmonitored parts of the sub-area.

Figure 5. Example of the stratification scheme used in the High Plains Regional Ground-Water Study.

Hydrogeology within a sub-area is expected to be relatively uniform from the regional perspective; therefore, data from monitoring networks in the sub-area presumably can be extrapolated to unmonitored parts of the sub-area (spatial up-scaling). Winter (2001) has used the term "hydrologic landscape" to describe these sub-areas, a term which will be adopted here.

In the High Plains, each hydrologic landscape was divided into equal-area blocks (Scott, 1990), with each block containing one randomly located monitoring well (fig.6). The ground-water science component of the framework was implemented using monitoring-well networks nested within the hydrologic landscapes that were designed to address critical processes of regional importance like water and chemical travel times through the unsaturated zone and aquifer (fig. 5). Process studies nested within assessment studies provided the understanding necessary to explain and support up-scaling of assessment results.

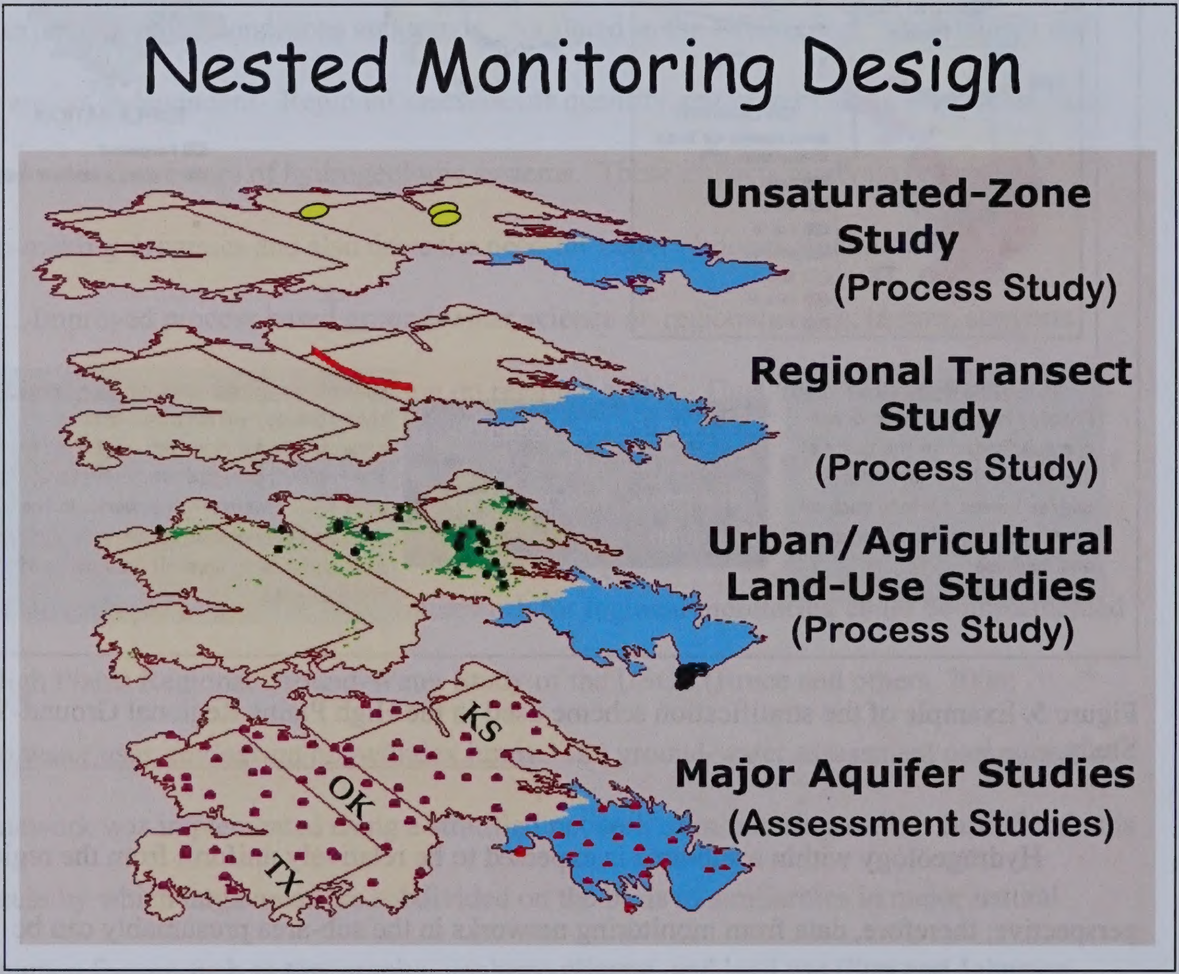

Nested Monitoring Design
Unsaturated-Zone Study
(Process Study)
Regional Transect Study
(Process Study)
Urban/Agricultural Land-Use Studies
(Process Study)
KS
OK
TX
Major Aquifer Studies
(Assessment Studies)

Figure 6. Example of the nested monitoring design used in the High Plains Regional Ground-Water Study (Central High Plains sub areas). Major Aquifer Studies provide assessment (baseline) understanding in each hydrologic landscape or sub-area. Nested within the Major

Aquifer Studies are monitoring-well networks designed to address critical processes of regional importance like water and chemical travel times through the unsaturated zone and aquifer, as well as measure effects from specific anthropogenic disturbances like urbanization and irrigated agriculture.

Monitoring data generally provide evidence of past and present human effects on water resources, but they cannot forecast future cumulative effects (temporal up-scaling). Determining how human effects on water quantity and quality will propagate through an aquifer requires knowledge of the directions and rates of ground-water movement. Numerical models of ground-water flow coupled with particle tracking are useful forecasting tools because they can synthesize the most current conceptual models with the best available hydrogeologic data in a quantitative fashion to show where ground water is likely to go and how long it will take to get there. Characterization of ground-water flow systems using numerical models also aids in spatial up-scaling of monitoring data by providing regional context to local flow systems in which monitoring networks may be located. Flow modeling and particle tracking have been used at the regional scale to understand recharge (Sanford and others, 2004), identify ground-water flow paths (McMahon and others, 2004), evaluate sources of water to wells and streams (Kauffman and others, 2001) (fig.7), and provide scenario-testing capabilities for different management options (Kauffman and others, 2001) (fig. 8), among other applications.

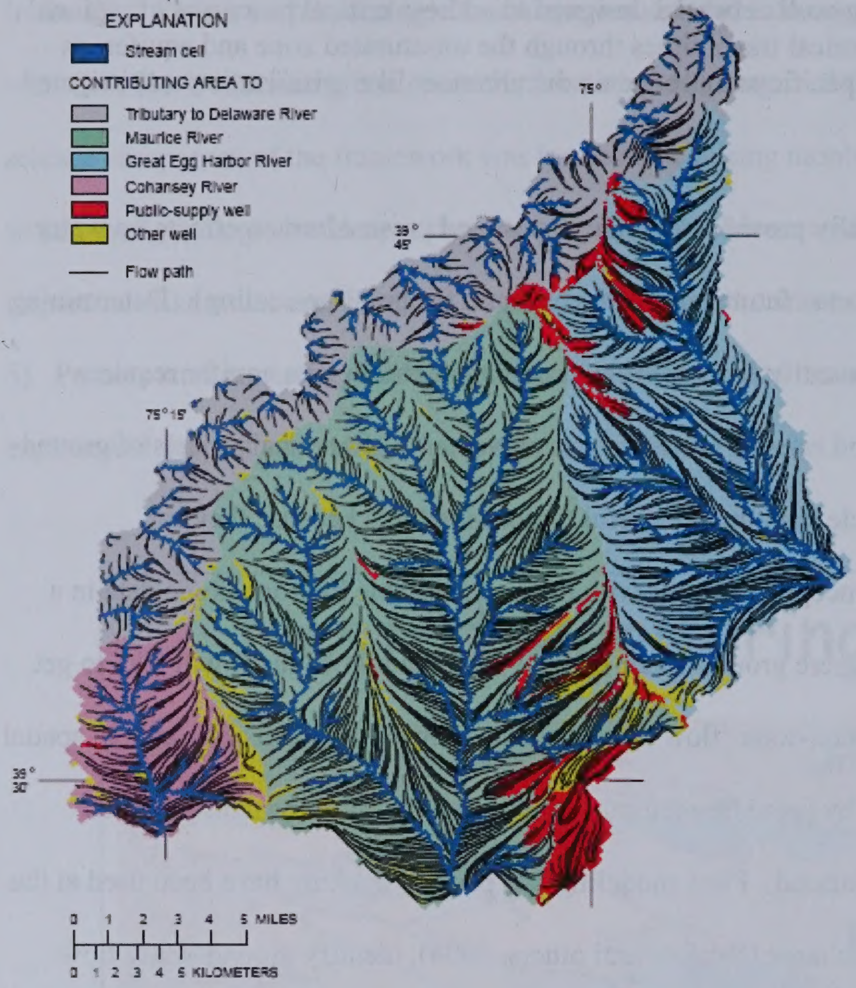

EXPLANATION
Stream cell
CONTRIBUTING AREA TO
Tributary to Delaware River
Maurice River
Great Egg Harbor River
Cohansey River
Public-supply well
Other well
Flow path
75°
39° 45'
75° 15'
39° 30'
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Figure 7. Simulated contributing areas to wells and streams and selected simulated flow paths in the Glassboro study area, New Jersey. (from Kauffman and others, 2001)

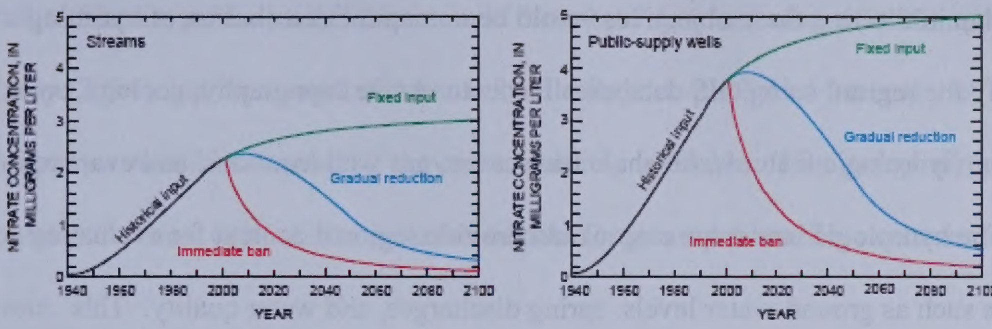


Figure 8. Simulated nitrate concentrations in streams and public-supply wells determined from historical nitrate input and simulated response to three management alternatives (fixed input, gradual reduction, and immediate ban) for future nitrate input in recharge, Glassboro study area, New Jersey. (from Kauffman and others, 2001)

The NRC concept of integrated ground-water assessment and ground-water science would provide the framework for regional monitoring of ground-water resources in the White River and Glenwood Springs Resource Areas of the Piceance Basin. A similar framework was adopted by the State of California to assess ground-water quality in major aquifer systems of the state (Belitz, 2003: http://ca.water.usgs.gov/gama/index.htm). The framework would be implemented using a stratified nested design (spatial up-scaling), coupled with numerical modeling and particle tracking (spatial and temporal up-scaling). A key requirement of this monitoring program is that it be linked with the resource-management process to provide the objective, timely, and relevant information needed to balance energy development with water-resource protection.

Phase I: Integrate Existing Data and Models

The primary objectives of Phase I are (1) develop a preliminary understanding of the regional hydrologic system through the use of models and existing information, (2) identify data gaps in the understanding, (3) identify indicators of energy impacts on water resources, and (4) design new monitoring programs to fill data gaps and begin trend monitoring for indicators.

The first step in meeting these objectives would be to map the distribution of hydrologic landscapes (stratify the region) using GIS databases for features like topography, geology, soils, climate, vegetation, hydrologic features, oil-shale lease areas, gas well locations, and evaporation pond locations. The hydrologic landscape map would provide regional context for evaluating other existing data such as ground-water levels, spring discharges, and water quality. This analysis forms the basis for developing preliminary conceptual and numerical models of water movement in the regional hydrologic system. The hydrologic landscape map and numerical models of water movement will be the primary tools for evaluating (up-scaling) data from nested monitoring networks in the regional context (Phase III).

The types and sources of data for ground-water quantity and quality in the White River and Glenwood Springs Resource Areas are extensive. Data have been collected, and in some cases analyzed, by local, state, and federal governmental agencies as well as by the energy industry. Table 11 lists examples of the types and sources of existing ground-water data. Important ancillary data that are relevant to ground-water issues, such as locations of roads, well pads, and evaporation ponds, are available electronically and discussed in the "Surface Disturbance" portion of this document. Available existing data would be gathered, assessed for their accuracy, and entered into a common data repository prior to analysis. In addition to gathering and analyzing existing data, it would be important to assess the current level of understanding of the ground-water flow system to both expedite the analysis of existing data and to guide new data collection. This assessment would require a thorough review of previously published interpretive ground-water studies. Some of the interpretive studies published as part of the first oil-shale development effort include the reports by Coffin and others (1971), Taylor (1982, 1987), Alley (1983), and Butler (1985). The number of recently published interpretive studies that are publicly available include those by Payne and others (2000) and Ramey and Hardy (2004), but the overall number is small. Reports published internally by the energy companies would be assessed if they were publicly available. That group of reports probably contains the most current interpretation of data for ground-water flow systems in the Piceance Basin.

Table 11. Examples of the types and sources of ground-water data available for the White River and Glenwood Spring Resource Areas. This list is not comprehensive.

Collecting Agency/Company	Description of data	Available in electronic format
• Colorado Division of Wildlife	Spring locations and possibly flow	Yes, but not all
• Colorado Oil and Gas Conservation Commission	Chemistry of ground water, chemistry of produced waters, locations of oil and gas wells, and more	Yes, but not all
• Colorado Department of Public Health and Environment	Locations of permitted monitoring, domestic, and irrigation wells; surface-water chemistry; and more	Yes, but not all
• Bureau of Land Management	Locations of springs, wells, and energy infrastructure; water chemistry, and more	Yes, but not all
• U.S. Geological Survey	Locations of springs and wells; water levels; water chemistry for streams, springs, ground water; chemistry of produced waters; geophysical and lithologic logs; hydraulic information; chemical data for oil-shale retorting; and more	Yes, but not all
• Shell Frontier Oil and Gas, Inc.	Water levels, ground-water chemistry, geophysical and lithologic logs, hydraulic information, chemical data for oil-shale retorting, and more	Unknown
• Encana Oil and Gas (USA), Inc.	Chemistry of ground water, chemistry of produced waters, locations of oil and gas wells, and more	Unknown

A detailed description of the methods that would be used to develop numerical models of ground-water movement in the study area is beyond the scope of this document, however, several examples of monitoring in support of modeling, and vice versa, are available in the literature for reference (Sanford and others, 2004; Johnson, 2007). During development of the hydrologic landscape map and the conceptual and numerical models, data gaps may be identified related to climate, geology, water levels, water chemistry, ground-water age, recharge, or hydraulic properties that require collection of new information. Those factors represent the ground-water science component of the framework. Data collection related to those factors would be used to refine understanding of baseline conditions of ground-water quantity and quality and to improve the conceptual and numerical models. New monitoring programs based on a stratified nested design would be developed to fill data gaps. Monitoring would begin in Phase II. Whenever feasible, new monitoring programs should be coordinated with existing programs to optimize the use of existing wells, sampling programs, and equipment.

A primary product of the analysis of existing information and development of preliminary models is a list of indicators of energy impacts on water quantity and quality. The indicators would be evaluated relative to land health standards, ambient ground-water quality standards, and other relevant health/management standards and goals. The stratified nested network of wells would be used to begin trend monitoring for those indicators in Phase II. Possible indicators could include ground-water levels, spring discharge, specific conductance, and selected organic water-quality parameters. As part of the effort to define indicators of energy impacts, an integrated team of managers, industry representatives, and scientists would periodically review existing data and modeling results to keep parties informed and focused on management objectives.

Phase I tasks, time estimates, and personnel requirements are listed in Table 12. Table 13 lists the expected products from Phase I.

Table 12. Tasks associated with Phase I and approximate time and personnel requirements for completing tasks.

Task	Time requirement	Personnel requirements
• Find relevant existing data, assess accuracy, and add to common data repository	12 months	Junior hydrologist, GIS specialist, students
• Make Hydrologic Landscape map	3 months	Senior hydrologist, GIS specialist
• Analyze water-level and chemical data in context of hydrologic landscapes	6 months	Hydrologists (senior and junior), GIS specialist
• Create preliminary conceptual models to illustrate and explain factors controlling the movement and chemical quality of ground water	3 months	Hydrologists (senior and junior)
• Create preliminary numerical model of ground-water movement as a tool to forecast regional effects of energy development on ground-water resources	18 months	Hydrologists (senior and junior), GIS specialist, student
• Identify data gaps. Coordinate with existing monitoring programs and develop new monitoring programs to fill data gaps. Monitoring would begin in Phase II.	9 months	Hydrologists (senior and junior), GIS specialist
• Use data and models to identify ground-water quantity and quality indicators of energy impacts. Evaluate indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals. Establish preliminary baseline for indicators.	6 months	Hydrologists (senior and junior)
• Develop trend-monitoring program for indicators. Monitoring would begin in Phase II.	3 months	Hydrologists (senior and junior)
• Review of existing data and modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives	At least twice during Phase I	Senior hydrologist
TOTAL TIME REQUIRED FOR PHASE I	**18 months**	--

Table 13. Expected products from Phase I.

PRODUCTS
• Common data repository.
• Hydrologic Landscape map.
• Preliminary conceptual model of ground-water movement and quality.
• Preliminary numerical model of ground-water movement.
• List of indicators of energy impacts on ground-water resources.
• Monitoring plans to fill data gaps and initiate trend monitoring for indicators.
• Interpretive report evaluating baseline conditions of ground-water quantity and quality.
• Interpretive report evaluating indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management standards and goals.

Phase II: Begin Monitoring and Expand Predictive Capabilities

The primary objectives of Phase II are (1) improve understanding of baseline conditions for indicators, (2) implement trend monitoring for indicators, and (3) expand the predictive capabilities of tools (primarily Hydrologic Landscape map and models) that would be used for spatial and temporal up-scaling of monitoring results in Phase III. The first two objectives represent the ground-water assessment component of the framework. The third objective represents the ground-water science component of the framework.

Phase II is considered to be an important intermediate step between evaluation of existing data (Phase I) and fully implementing a monitoring program (Phase III) because it would expand understanding of baseline conditions for indicators prior to fully implemented trend monitoring for indicators. Tools for up-scaling monitoring data would be tested during Phase II. Feedback from this analysis would be used to update the list of indicators and revise monitoring plans and modeling tools.

An important task near the end of Phase II is an assessment of the monitoring network in terms of its adequacy with respect to areal coverage and sampling frequency. A detailed description of the tools and methods used in that analysis is beyond the scope of this document, however, several examples of their application to other ground-water monitoring networks are available in the literature for reference (Candela and others, 1988; Swain and Sonenshein, 1994). This task is necessary to optimize the final monitoring network implemented in Phase III. This analysis could result in the expansion or contraction of well networks.

Phase II tasks, time estimates, and personnel requirements are listed in Table 14. Table 15 lists the expected products from Phase II. The timeline for Phase II is somewhat dependent on the availability of data from the energy industry, which would be determined during Phase I. It is likely that the energy industry has the most recent and detailed data on ground-water chemistry, hydrostratigraphy, and hydraulic parameters. If those data are made available, it could save substantial time and money in implementing the framework. If those data are not available, then they might have to be collected during Phase II.

As in Phase I, an integrated team of managers, industry representatives, and scientists would periodically review data and modeling results to keep parties informed and focused on management objectives.

Table 14. Tasks associated with Phase II and approximate time and personnel requirements for completing tasks. The time requirements assume that some, but not all, data collected by the energy industry are available for analysis.

Task	Time requirement	Personnel requirements
• Implement nested monitoring program to fill data gaps and begin measuring trends in indicators	18 months	Hydrologic technicians, Junior hydrologist, GIS specialist
• Revise Hydrologic Landscapes map	3 months	Senior hydrologist, GIS specialist
• Expand understanding of baseline conditions for indicators	6 months	Hydrologists (senior and junior), GIS specialist
• Revise conceptual and numerical models	18 months	Hydrologists (senior and junior)
• Update list of indicators	3 months	Hydrologists (senior and junior), GIS specialist, student
• Evaluate monitoring programs and revise as needed	3 months	Hydrologists (senior and junior), GIS specialist
• Review of existing data and modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives	At least twice during Phase II	Senior hydrologist
TOTAL TIME REQUIRED FOR PHASE II	**18 months**	--

Table 15. List of Phase II Products.

PRODUCTS
• Updated Hydrologic Landscapes map.
• Revised conceptual model of ground-water movement and quality.
• Revised numerical model of ground-water movement.
• Updated list of indicators of energy impacts on ground-water resources.
• Revised monitoring plan for filling data gaps and measuring indicators.
• Interpretive report evaluating indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management standards and goals.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

The stratified nested monitoring program is fully implemented in Phase III to (1) measure trends for indicators of energy impacts on ground-water quantity and quality (ground-water assessment) and (2) refine predictive tools (ground-water science). Monitoring results are interpreted in the regional context provided by the Hydrologic Landscape map and models so that cumulative effects of energy development on regional water resources can be assessed. One outcome of this assessment could be identification of water resources that are impaired by energy development. In that case, corrective action may be required, followed by performance monitoring.

Development of a stratified nested monitoring program for the White River and Glenwood Springs Resource Areas is beyond the scope of this document, however one example of a stratification scheme is outlined here for illustrative purposes. Major strata could include the following:

(1) Topography/vegetation (controls on recharge/discharge),

  a. Uplands/forest

   b. Slopes/grasses

   c. Valleys/sagebrush, riparian vegetation

(2) Hydrogeology (controls on water quantity, quality, and movement)

   a. Alluvial aquifer

   b. Upper bedrock aquifer

   c. Lower bedrock aquifer

(3) Land use (controls on water quantity and quality).

   a. Oil shale development

   b. Natural gas development

   c. Rangeland

Ground-water assessment studies in one or more of these major strata would provide baseline and trend data for indicators. Strategically designed ground-water science studies nested in one or more of the strata could address regionally significant processes like downward leakage of chemicals from evaporation ponds, upward leakage of chemicals from deep formations, ground-water travel times, fate of injected water, and ground-water/surface-water interactions. Process studies nested within the assessment studies would provide:

1) Understanding necessary to refine models and explain and support up-scaling of assessment results.
2) Ability to differentiate between natural and human factors.
3) Understanding necessary to support better management decisions.

Phase III tasks and personnel requirements are listed in Table 16. Table 17 lists the expected products from Phase III. The timeline for Phase III would depend on several factors that cannot be determined at this time, including extent and duration of energy development and the magnitude of energy impacts on the regional hydrologic system.

As in Phases I and II, an integrated team of managers, industry representatives, and scientists would periodically review data and modeling results to keep parties informed and focused on management objectives.

Table 16. Tasks associated with Phase III and approximate time and personnel requirements for completing tasks. The time requirements assume that some, but not all, data collected by the energy industry are available for analysis.

Task	Time requirement	Personnel requirements
• Fully implement revised monitoring program and continue trend monitoring for indicators	To be determined	Hydrologic technicians, Junior hydrologist, GIS specialist
• Forecast (spatial and temporal up-scaling) regional effects of energy development on water resources	To be determined	Senior hydrologist, GIS specialist
• Evaluate indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals	To be determined	Hydrologists (senior and junior), GIS specialist
• Identify corrective action needs	To be determined	Hydrologists (senior and junior)
• Integrated team of managers, industry representatives, and scientists develop and implement corrective actions (Best Management Practices, BMPs)	To be determined	Hydrologists (senior and junior), GIS specialist, student
• Performance monitoring of BMPs	To be determined	Hydrologic technicians, Junior hydrologist, GIS specialist
TOTAL TIME REQUIRED FOR PHASE III	To be determined	--

Table 17. List of Phase III Products.

PRODUCTS
• Tools for evaluating monitoring results in regional context.
• Monitoring program that integrates ground-water assessment (baseline and trends) and ground-water science (understanding).
• Interpretive reports evaluating indicators relative to land health standards, ambient ground-water quality standards, and other relevant health/management goals.
• Interpretive reports explaining monitoring results in framework of controlling natural and anthropogenic factors.

Surface Disturbance Monitoring Related to Energy Development

The most conspicuous environmental impact of oil and gas development is land disturbance. Surface disturbance from energy development includes both the physical equipment introduced into the landscape as well as the ground from which vegetation has been removed. Because oil and gas exploration, development, and reclamation occur continuously in the Piceance structural basin, the patterns of surface disturbance are constantly changing in this region.

The BLM presently evaluates energy development impacts (including surface disturbance) under the Federal Land Policy and Management Act (FLPMA) of 1976. Its organizational mandate is to manage multiple-use public lands so that the Nation's need for oil and gas resources is balanced with other resource values to best meet the present and future needs of the American people. BLM assesses energy impacts at both regional and local scales. BLM regional-scale assessments occur during preparation of National Environmental Policy Act (NEPA)-related documents, Resource Management Plans (RMP's), and Reasonable Foreseeable Development (RFD) technical reports. RFD's, for example, include acreage estimates prepared by petroleum engineers and geologists for development of large resource areas (such as the Roan Plateau). More localized BLM assessments occur during processing of applications for permit to drill (APD's). To evaluate APD's, GIS or GIS -based decision tools, such as CARAT (Computer-Aided Resource Assessment Tool),[1] are used to compare the lease location against development stipulations and other land-use needs.

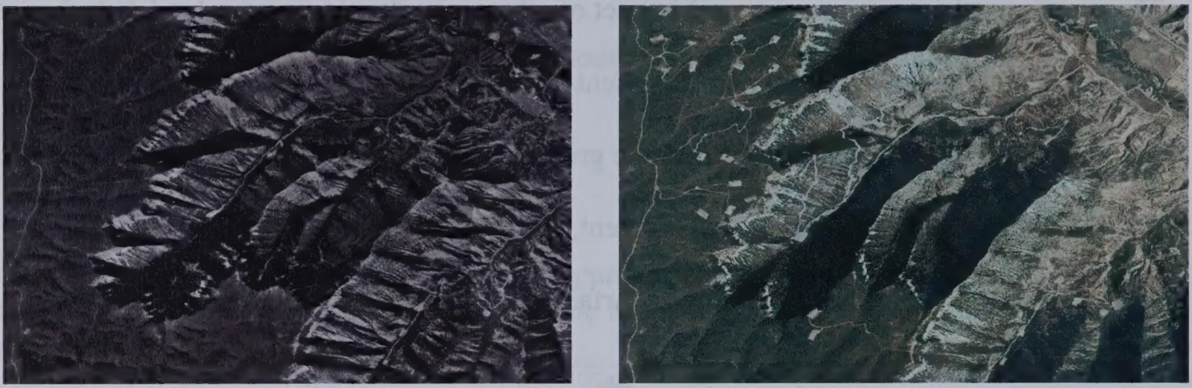


Figure 9. Area west of Parachute Creek and southwest of the Roan Plateau showing past surface disturbance (left photo, 1993) and more recent (right photo, 2005).

Although the BLM presently assesses impacts from oil and gas development, surface disturbance in the Piceance structural basin is particularly intense, both spatially and temporally, and its potential impacts on water and wildlife are poorly understood. Potential impacts are certainly reduced by the energy industry's use of BMP's, such as using smaller well pads and access roads, directional drilling, centralizing production facilities, burying pipelines and utility lines, and generally practicing good land reclamation and land stewardship. Still, the combined and long-term effects of such concentrated disturbance are poorly known for this region because of the present lack of an overarching monitoring plan and ongoing data collection, synthesis, and analysis. Such concentrated, rapid development has the potential to impact water resources:

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[1] CARAT is presently used by the White River and Pinedale field offices. The BLM expects that APD's will be evaluated in the future using the ePlanning version 2 GIS toolkit to be developed by DOE's National Energy Technology Laboratory and to be deployed, at least in proof-of-concept form, in 2007.

- High well and road densities cause locally focused patterns of vegetation loss that could alter groundwater infiltration rates and long-term rates of soil erosion. Little is known about how such exposed areas cumulatively affect long-term water quality (Spahr, et al., 2000, Albrecht, 2007) or the biological integrity (Stoddard, et al., 2004) of intermittent or perennial streams in this region. Aquatic habitat is particularly fragile in such semi-arid streams, and it may, over time, be especially vulnerable to increased sediment loads during storm events.
- The scale of development increases the potential for improper disposal of drilling fluids, cuttings, and water and also raises the potential for surface water or groundwater contamination. Water quality and riparian habitat data for this region, once again, are sparsely collected and not consolidated. Therefore, judgments regarding the ramifications of surface disturbance on water quality and stream habitat are somewhat speculative and based on investigations in other areas.

Surface disturbance from oil and gas development in the Piceance structural basin also has potential effects on wildlife habitat, including:

- Overall increased cumulative noise, air, water, and light pollution effects at well sites and on roads, with unknown persistent consequences on bird and mammalian species.
- Facilitated entry of so-called synanthropic species (species that benefit from human activity), that access and move about the landscape more easily via pipeline and road corridors. (Leu, Hauser, and Knick, 2003). Such human-aided species include bird and mammalian predators (such as magpies and foxes), and displacing species, such as non-native plants.

- A decrease in size of patches of habitat and an increase in the distance between habitat areas (Noss and Csuti, 1994). Landscape fragmentation decreases actual and functional habitat, and is widely acknowledged as detrimental to indigenous wildlife and plant species (Knight, et al., 2000; McGarigal and Marks, 1995).

Periodic mapping of surface disturbance from oil and gas development is integral both to present BLM work and to the proposed monitoring. At a very minimum, repeated mapping provides an overview of current (and potentially historical) land disturbance and of the progress of reclamation. Also, BLM integration of land-use needs under FLPMA can only be done using up-to-date and accurate GIS surface disturbance information. From the standpoint of the needs of the monitoring program, surface disturbance locations provide a backdrop of spatial information that guides interpretation of habitat and water quality analyses. Surface disturbance parameters - percentages of disturbance, spatial density metrics (road and well density), distance metrics, and habitat fragmentation metrics - are needed to analyze and monitor effects of disturbance on water and wildlife. Such parameters are used for watershed modeling, for studies of changes in rates of erosion, for terrestrial habitat studies, and even for investigations of groundwater recharge zones.

Surface disturbance can be inventoried as five GIS data themes. Four are vector GIS data themes related to oil and gas development: access roads, well sites, processing plants and other larger production facilities, and pipeline routes[2]. The vector data themes do not change at the same rate –access roads and wells datasets, for example, require more frequent updates because of new drilling and reclamation[3]. A fifth needed data theme is a measure of 'bare ground' (disturbed and natural) versus other land-use or vegetation categories. This raster land-use measurement of surface disturbance is needed at various scales for monitoring program components, especially for landscape fragmentation and erosion studies. BLM field offices presently use most or all of these data themes (see Appendix), however the monitoring program will need improvements to data collection mechanisms, most of which would also help the present BLM workflow:

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[2] Although they may be buried and eventually revegetated, gathering lines will have temporary surface disturbance, and it is useful to record their locations as a surface disturbance layer and for water quality monitoring.

- Because of the scale and pace of surface change in this area, vector data themes, especially access roads and well locations, need to be updated frequently. A data capture protocol needs to be developed to ingest, update, and consolidate accurate surface disturbance data more easily and on a regular basis.
- Vector data themes need to be consolidated from various sources. For example, available roads datasets should be compared for accuracy and combined if possible into a common data structure, one compatible with in-place BLM workflow and GIS decision tools.
- Data gaps should be identified. Such gaps include both spatial 'holes' as well as missing parameters needed for monitoring. As an example, several additional road parameters would be needed for WEPP erosion modeling.[4]
- Bare ground and other land-use/vegetation categories need to be periodically remapped for monitoring. Such mapping is needed at the scale of the entire Piceance

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[3] Although the new Rockies Express gas pipeline, which will be completed in 2009 to connect Meeker, Colorado to Clarington, Ohio, proves that the other, more 'stable' vector data themes are also changing due to the rapid pace of Piceance Basin energy development.

[4] Road parameters include: road surface (natural, gravel, paved), traffic level, road gradient, road width, fill slope gradient, fill slope length, buffer gradient, buffer length, soil texture, percent of rock in soil, and road section length (high point to drainage point (low point, culvert, cross bar, etc.).

structural basin and for small study areas (i.e., for WEPP "hillslope" drainages which vary in size from tens to a few hundred square kilometers).

Much of the first phase of the surface disturbance work will entail determining which combination of data capture methods is the most effective and economical. Surface disturbance data can be captured and updated in three basic ways, each involving different skills and personnel requirements:

- GPS data collection of vector data. For the Piceance structural basin, GPS locations of roads and all oil/gas facilities are being collected annually by the two counties in which energy development is primarily occurring.[5] As another example, energy companies provide GPS locations of planned and actual wells to the Colorado Oil and Gas Conservation Commission, from which Colorado BLM offices acquire well location data. GPS data collection is an inexpensive means of filling spatial data gaps and of collecting additional data parameters.
- Manual vector feature delineation by interpretation of aerial photography or high-resolution satellite imagery. Periodically collected orthophotography is available as part of a national program, USDA's National Agricultural Imagery Program (NAIP). The BLM White River Field Office, for example, recently updated their roads and trails layers using 2005 NAIP imagery. In this region, however, NAIP presently is collected with a 5-year repeat frequency, a cycle that may be too long to monitor the rapid Piceance basin energy development. Another disadvantage to NAIP imagery is that it is not color-infrared, although special acquisition of such imagery can be negotiated at additional cost. If inexpensive aerial photography is available, manual digitizing of vector features is labor intensive but can be cost effective. Manual

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[5] Rio Blanco and Garfield counties.

feature delineation from imagery combined with data collected annually by local counties via GPS may be an economical way to periodically update vector data themes.

- Automated delineation of raster bare ground and of vector data themes from imagery. Automated classification of medium-resolution LANDSAT ETM+ 1999 to 2003 imagery,[6] for example, was used to produce NLCD2001, Southwest Regional Gap, and LANDFIRE land-use/vegetation categories (see Appendix). The panchromatic band of high-resolution imagery optionally could be used to enhance the resolution of medium-resolution imagery and map bare ground. To develop finer-grained maps of bare ground and other land use for small study areas, aerial photography or high-resolution satellite imagery[7] can be collected and analyzed economically. In addition to bare ground, vector features could also be updated using automated methods and NAIP or high-resolution satellite imagery. Satellite imagery, for example, has been used successfully to vectorize roads, pipelines, and well pads in parts of the Powder River Basin (McBeth, pers. comm., 2007). The advantages of automated extraction of vector data include savings in personnel time. The disadvantages are that some cleanup of the extracted features probably would be involved, and if high-resolution satellite imagery is used as the base, the imagery has a relatively high cost for large areas. However, vector data can be extracted from the same base imagery used for manual digitizing, and such features provide a better starting place for manual digitizing.

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[6] On 31 May 2003, the Landsat Enhanced Thematic ETM + instrument began to malfunction, causing the imagery to exhibit wedge-shaped gaps between scan lines which vary in size across a scene. The monitoring program will have to evaluate whether current LANDSAT is still accurate enough for land-use classification or whether other medium-resolution satellite imagery is more suitable.

[7] Digital Globe or GeoEye high-resolution commercial saetellite imagery products. Such products vary in spatial resolution from 0.6m (Digital Globe Quickbird) to 1m (GeoEye IKONOS) for panchromatic band and 2.5m (Quickbird) to 4m (IKONOS) MSS bands. A new GeoEye satellite, GeoEye-1, scheduled for summer 2007 launch will provide .41m panchromatic and 1.65m MSS imagery.

Phased Management Plan for Surface Disturbance

Surface disturbance dataset development would be integrated in the same three phase structure described elsewhere in this report for all monitoring components. It should be noted that each phase consists of a stage of work and does not necessarily equate to a single year of time.

Phase I: Integrate Existing Data and Models

Phase I, for the monitoring components in general, is a data collection and evaluation phase. At the beginning of Phase I, current BLM workflow and the monitoring program would be analyzed to inventory the specific surface disturbance metrics and data themes needed and to decide how often updates are needed. Existing vector surface disturbance GIS datasets would be collected from various sources, including any datasets available from energy companies. These datasets would also be examined for quality, for spatial data 'holes,' and for missing parameters/data attributes needed by the monitoring program. These additional data attributes would be collected using GPS, and GPS may be used to fill in spatial gaps as well. During Phase I, vector GIS datasets for each surface disturbance data theme (roads, well pads, other production facilities, and pipelines) will be evaluated to determine what related datasets could be consolidated into a common data structure that would be made compatible with existing GIS decision tools. For updated or refined regional land-use/vegetation categories, medium-scale satellite imagery also would be obtained. For smaller study areas/drainages, high-resolution satellite imagery or aerial photography would be acquired to generate detailed raster bare ground/land use categories and optionally to try to generate vector features. Also, costs would be determined for participating in the existing national NAIP aerial photography program), specifically for obtaining a color-infrared product, a shorter repeat frequency, and 1m-resolution imagery for the Piceance structural basin. Tables 18 and 19 below detail the tasks, time requirements, and products expected from this initial phase of work.

Table 18. Tasks associated with Phase I and approximate time and personnel requirements for completing tasks.

Task	Time requirement	Personnel requirements
• Develop an understanding of the current BLM field office work flow and determine specific surface disturbance metrics required for the present BLM workflow and for the monitoring plan and how often they each should be updated.	1 month	GIS specialist, database analyst, BLM resource specialists, monitoring program specialists
• Acquire and inventory data quality of surface disturbance datasets: roads, wells, pipelines, and larger production facilities from BLM, State, local, and private sources. Identify the most accurate datasets and data gaps.	1 month	GIS specialist, BLM GIS specialists
• Develop a common data structure to merge good quality surface disturbance vector data themes and integrate the data structure into any in-place GIS-decision making tools.	8 months	GIS specialist, database analyst, BLM resource specialists, BLM GIS specialists
• Collect GPS vector data for missing parameters needed by the monitoring program for small study areas. Optionally test the use GPS to collect locations of roads, wells, processing facilities, pipelines in spatial data gaps.	1-2 months	GIS specialist, modeling specialists, students
• Acquire and prepare medium-resolution, regional satellite imagery for deriving bare ground and other land use categories; also field collection using GPS of training areas.	2-3 months	Remote sensing specialist(s)
• Acquire and prepare high resolution satellite orthoimagery for small areas to derive bare ground and other fine-grained land-use categories; also field collection using GPS of training areas to use in classification.	2-3 months	Remote sensing specialist(s), other monitoring component specialists for help w/ categories
• Evaluate the cost/benefits of partnering with NAIP program to acquire color infrared imagery, shorter repeat collections (2-3 years) and/or 1-m resolution aerial photography for	2 weeks	GIS specialist

the Piceance structural basin area.		
TOTAL TIME REQUIRED FOR PHASE I	**16-19 months**	--

Table 19. Expected products from Phase I.

PRODUCTS
• List of specific surface disturbance datasets and metrics needed for land assessments and by the monitoring program.
• Consolidated data structures for individual vector surface disturbance datasets: roads, wells, pipelines, and oil/gas facilities.
• Acquired medium-resolution satellite imagery for the overall Piceance structural basin.
• Acquired high-resolution satellite imagery for two watershed monitoring areas.
• Cost/benefit analysis of acquiring improved, more frequently collected aerial photography via the existing NAIP program.

Phase II: Begin Monitoring and Expand Predictive Capabilities

During Phase II monitoring will begin. Surface disturbance GIS vector data themes, such as roads, will be combined as much as possible. During this phase, automated methods to develop surface disturbance raster (and possibly also vector) data from imagery will be developed, and the time frames required will depend on the scope of the need and the method used. Data developed from imagery processing will be geared primarily to support the terrestrial habitat, watershed, erosion, and groundwater modeling that will begin during this phase. Also in Phase II, a protocol will be developed to facilitate updates of surface disturbance data. Tables 20 and 21 itemize the expected tasks and deliverables from this phase.

Table 20. Tasks associated with Phase II and approximate time and personnel requirements for completing tasks.

Task	Time requirement	Personnel requirements
• Combine related datasets into single datasets by theme. The data structures of the combined layers will be made compatible with GIS decision-making tools in use by the BLM	3 months	GIS specialist, database analyst, BLM GIS specialists

offices.		
• Develop a methodology for mapping detailed bare ground/land-use categories for small study areas using aerial photos or high-resolution satellite imagery. Optionally develop a method for extracting vector features.	4 months	Remote sensing specialist(s)
• Develop a method to map medium-resolution land-use categories for entire Piceance structural basin.	4 months	Remote sensing specialist(s)
• Establish partnership with NAIP program to acquire improved and more frequently collected imagery.	2 weeks	GIS specialist
• Develop and begin testing a conceptual protocol/mechanism to recurrently capture and integrate surface disturbance data into the BLM land assessment and monitoring programs.	4 months	GIS specialist, database analyst
TOTAL TIME REQUIRED FOR PHASE II	**17 months**	--

Table 21. List of Phase II Products

PRODUCTS
• Combined and complete roads, wells, pipelines, and oil/gas facilities spatial datasets.
• Map of bare ground and other land use categories in overall Piceance basin and documentation of methodology used.
• Map of bare ground and other land use categories in small study areas for model inputs and documentation of methodology used.
• Documentation for a mapping protocol for extracting raster bare ground and optionally for extracting vector features from imagery.
• Preliminary protocol for importing and updating digital surface disturbance data that meets the needs of BLM assessments and of developing monitoring programs.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

During Phase III, monitoring will be fully implemented to test for impacts to water and wildlife resources. Because this phase relies heavily on the outcomes of Phases I and II, specific tasks, products, and time requirements are not yet known. Phase III is envisioned at this point to continue updates of surface disturbance data (which the BLM may do internally or chose to contract) and also implementing a data update protocol.

Table 22. Tasks associated with Phase II and approximate time and personnel requirements for completing tasks.

Task	Time requirement	Personnel requirements
• Continued, ongoing integration of surface	To be	GIS specialist, students

disturbance data from various sources into single data themes.	determined	
• Possibly ongoing GPS collection of roads and oil/gas facilities information for areas not annually updated by county governments.	To be determined	GIS specialist, students
• Possible acquisition on a periodic basis (possibly 2-3 yrs) new aerial photo or satellite imagery: medium and high resolution to update vector features and/or bare-ground categories for monitoring plan.	To be determined	GIS specialist, remote sensing specialist(s)
• Testing and implementation of data updating protocol for surface disturbance data.	To be determined	GIS specialist, database analyst
TOTAL TIME REQUIRED FOR PHASE III	To be determined	--

Table 23. List of Phase III Products.

PRODUCTS
• A plan and a tested mechanism for periodic collection and updating of surface disturbance data based on the needs of the organization.
• Assistance, if needed, with data acquisition and updates, especially with deriving surface disturbance products from periodically collected imagery.

Regional Approach to Modeling Related to Energy Development: Case Study for Water-Quality and Erosion Modeling

The data accumulated through the implementation of a monitoring program can be used to identify: current conditions, trends in relation to past conditions, or as a template from which forecasts of probable conditions can be made. Although assessing trends and conditions are important to understanding the health of an area of interest, the BLM is most interested in predicting the cumulative effects of energy development on an area. A means of prediction advocated by the National Research Council (NRC) in its publication "Opportunities to improve the U.S. Geological Survey National Water Quality Assessment Program," is the use of water quality models to predict, both spatially and temporally, the effects of anthropogenic changes on environmental health (NRC, 2002). The NRC go on to state that, "Understanding and prediction, embodied in water-quality models, are the cornerstones of water resources management for the future" (p122).

The benefits of using a water-quality model to better understand an area is that the land managers have a tool with which to assess the current conditions of the area, identify important environmental processes, and examine the effects of proposed changes in management. Historical data is used to develop a model and a conceptual understanding of the environmental processes occurring in the area of interest. During model development the validity of the conceptual understanding can be tested to ensure the correct processes are being simulated. By validating the conceptual understanding more confidence can be had that results obtained from model simulations are realistic of actually occurs. The confidence gained also improves the reliability of the model when it is changed to examine the effects of various potential management scenarios. The results of these simulations would seek to answer questions identified in the monitoring plan and would identify how changes in land use, soil properties or stream networks might influence the area.

Water-quality models can take several forms. The models can vary from simple regression models that simulate specific environmental processes at specific points and times, to theoretically complex, fully distributed models that can simultaneously predict numerous processes at any number of places and times. The complexity of the model should be considered early in the modeling process and should reflect the objectives of the monitoring plan. Unless the results of a complex model address the relevant questions a simpler model is preferred. When modeling systems where water quality is a concern, hillslope models, in-stream or hydraulic models, or watershed models are often used. While these types of models can be developed for the specific area of interest the process can be laborious and may produce results the integrity of which may be questionable to the scientific community. Fortunately, there are numerous water-quality models available that are often free and produce reliable, respected results. An extensive list of contemporary models has been made available by Singh in his book "Watershed models" (Singh, 2005). An additional list of models is available on the Internet from: http://www.wiz.uni-kassel.de/model_db/models.html (accessed 5/7/07)

As the modeling is being conducted to answer questions using data collected as part of the monitoring program is essential to consider the data requirements of the model or models when developing a monitoring program. Specifically, the temporal and spatial scales at which models will be developed must be identified. By identifying the data requirements of a model prior to implementing a monitoring program the value of the monitored data can be increased. Admittedly more data is always better than less, but for example, if a model requires daily data it is inefficient to collect data at a smaller time-step. Deciding on the temporal scale to work with is relatively straight forward when considering the questions the monitoring program is designed to address. For in-stream water-quality it is common to use a daily time-scale because of the total maximum daily load requirements established by the US Environmental Protection Agency.

Selecting the spatial scale(s) to model requires considering how indicative the environmental processes occurring in small areas within the area of interest are of processes occurring throughout the area of interest. If a small area is deemed representative of adjacent smaller areas or the larger area then a model may only need to be developed for the representative small area. Correspondingly, a more intensive monitoring network would be installed in the smaller area than in other parts of the large area. An example pertinent to assessing the effects of energy development on an environment would be to develop a model for a watershed in which energy development will occur and develop another model for a watershed in which no development will occur. Modeling the two systems would facilitate the isolation of anthropogenic impacts on the environment. This approach corresponds to the paired watershed monitoring approach listed by the NRCS in the "National Handbook of Water Quality Monitoring" (NRCS, 1997).

With the above considerations in mind, it is possible to outline a framework by which a model can be selected and applied to an area. The outline has components of those presented by Beven (2001) and Abbott and Refsgaard (1996), and has been tailored to fit the other outlines presented in this document and consists of a three-phased approach. The majority of modeling work would be conducted in the first phase. Improvements and alterations to the models would be made in the successive phases as new objectives and scientific questions arise. The phases are as follows:

Phase I. Integrate Existing Data and Models
Phase II. Expand Predictive Capabilities
Phase III. Fully Implemented Modeling Program

Tasks within each of the phases of the modeling program are outlined in the following sections. To better illustrate how the tasks could be accomplished a potential modeling application addressing erosion and sediment transport processes will be described prior to explaining the next phase.

Phase I: Integrate Existing Data and Models

The primary objectives of Phase I for modeling are identical to those developed for the developing a regional ground-water monitoring program and are to (1) develop a preliminary understanding of the regional hydrologic system through the use of models and existing information, (2) identify data gaps in the understanding, (3) design new monitoring programs to fill data gaps, and (4) identify indicators of energy impacts on water resources. In general though, several tasks must be accomplished in Phase I when applying any model.

1) Establish areas and environmental variables to model. Identified by stakeholders when developing the monitoring plan through personal experience and available literature.
2) Find relevant, existing data and add to common data repository. The data would consist of temporal and spatial data available at coarse and fine resolutions and be subjected to a thorough quality-control analysis. Examples of temporal data and spatial data are listed below with temporal data listed as point data as it is often collected at a specific location.
    a. Point data
        i. Stream gages, climate stations, well locations, water quality recorders, atmospheric deposition collectors
    b. Line data
        i. Streams, roads, man-made waterways
    c. Areal data
        i. land-surface elevation, land use, soil, bedrock, surface and subsurface disturbances, chemical applications, land-ownership boundaries, grazing areas
3) Establish spatial and temporal boundary conditions for the area(s) to be modeled. These boundaries could take the form of identifying a topographic boundary, regional groundwater flow boundaries, the period of record to model, and extreme values of the environmental variable to be modeled.

4) Develop general mass balances of physical, chemical, and biological parameters for the area to be modeled based on available literature
    a. Analyze atmospheric, solid media, and dissolved and suspended particulate data in three-dimensions and through time.
5) Create preliminary conceptual models to illustrate and explain factors controlling the status and trends of physical, biological and chemical variables.
    a. Assess temporal and areal distribution of precipitation. Does evaporation exceed precipitation annually or seasonally? Does precipitation infiltrate or runoff? Does precipitation fall predominantly as snow?
    b. Analyze soils. Are they aniosotropic? Do preferential flow paths exist? Do restrictive layers exist? Do perched water-tables develop?
    c. Analyze temporal and spatial distribution of vegetation. Perennial or annuals? What are the rooting depth, density and size? Physical and chemical consumptive requirements?
    d. Analyze streamflows areally (gaining/losing reaches) and temporally to gain understanding as to where potential GW discharges may flow.
6) Identify potential models based on the conceptual models and the spatial and temporal data identified in Tasks 2 and 3, being sure to address:
    a. The need for model complexity (lumped vs. semi-distributed vs. fully-distributed, empirical vs. conceptual vs. physically-based, annual vs. seasonal vs. daily vs. event)
    b. The cost-effectiveness of selecting an available model versus developing a model independently

   c. The number of models required, which depends on the environmental variables for which modeling has been deemed necessary
   d. The ability of the model to be used for forecasting, upscaling or downscaling
   e. Restrictions due to the monitoring data strategy

It is essential to modeling success that the model selection process not be subjected to internal pressure recommending the use of specific models.

7) Create preliminary numerical models to simulate the fluxes of environmental variables.
   a. Gather and format necessary ancillary data. Further processing of GIS and temporal data may be required
   b. Identify environmental variables the data for which can be used in objective functions during calibration (streamflow, evapotranspiration, for example)
   c. Establish performance criteria considering the period of record available for temporal data, the location of the area being modeled, the mass balance created in task 4, and the performance criteria used by previous studies.
   d. Conduct a simulation
   e. Assess model performance and whether the model requires calibration. If so can the model be calibrated manually or does it require an automated optimization tool.
   f. Conduct a sensitivity analysis of model parameters
   g. Calibrate the model by adjusting parameters identified in the sensitivity analysis.
   h. Repeat steps **d – g** until either the performance criteria is reached or the model is unable to perform more efficiently.

    i. Validate the model by simulating a different period of record than used during the calibration and assessing the model performance identically. A model is validated if it meets the performance criteria.
    j. Quantify the error associated with model
    k. Compare modeled results to those expected when considering the conceptual model. Are they similar? If not, which model requires adjustment

8) Examine means of improving the modeling of environmental variables.
    a. Account for model performance and whether another model may perform better. Identify the data necessary to improve current model performance or apply a different model
    b. Determine whether upscaling or downscaling is required and identify the necessary data
9) Coordinate with existing monitoring programs and develop new monitoring programs to fill data gaps.
10) Coordinate with resource managers to identify surface-water quantity and quality indicators of energy impacts. Evaluate indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.

Several products will be completed following the completion of the tasks of Phase I. Perhaps most importantly the scientists will have a detailed understanding of the environmental processes at work. More tangible products from which to base further research will be the temporal and geospatial data and the calibrated models which will be used to make forecasts as to the impacts of energy development on the environment. A list of products is given below.

Products

1) Common data repository containing existing available data (start integrating data from all disciplines.)
2) Maps/GIS coverages of several environmental variables that control surface water movement and quality.
3) Preliminary conceptual model of environmental variables.
4) Preliminary numerical model of environmental variables.
5) List of indicators of energy impacts on surface-water resources.
6) Plans for monitoring programs to fill data gaps and for improved and more specialized modeling
7) Interpretive report evaluating baseline conditions of environmental variable quantity and quality.
8) Interpretive report evaluating indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.

Phase II. Expand Predictive Capabilities

With the initial models developed, calibrated, and validated it is possible to use the models to predict how the area of interest might respond to anthropogenic changes. The developed models are a means by which the effects of many scenarios of change can be evaluated in a relatively short time. An additional benefit is that the models provide an objective, scientific interpretation of the effects of change.

Designing a forecasting model involves a number of Tasks, as listed below. For forecasting with environmental models it is often necessary to be able to predict climate. Some models have weather generators built-in which use climatological statistics based on previous weather data to predict climatic variability. When weather generators are not available a method commonly used in environmental modeling for forecasting is ensemble predictions. To incorporate potential future climate conditions into a forecast statistically downscaled results of a forecasting global climate model have been used. Similar to the format of Phase I, an example of a forecasting application will be presented following the required Tasks.

Phase II: Expand Predictive Capabilities

1) Identify environmental variables for which forecasting trends is desired and develop trend-monitoring program for such variables.
2) Implement trend-monitoring program for indicators.
3) Periodic review of monitoring results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.
4) Forecast trends in environmental variables using validated models.
    a. Identify the method used to acquire data for forecasting. For example, ensemble variable prediction using previous data or output from another model.
    b. Identify scenarios that could potentially influence the environmental variables.

   c. Determine a range of influences within each scenario to include at least a minimal influence, an extreme influence, and a potentially unrealistic influence.
   d. Conduct simulations
   e. Analyze results and identify the simulated trends in the environmental variable.
5) Coordinate with resource managers to update indicators using model results. Evaluate indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.
6) Revise conceptual and numerical models with data from Task 1-3. Revise forecasts of regional effects of energy development on water resources.
7) Revise monitoring program to address new data needs.
8) Revise trend-monitoring program on the basis of Task 5.

Products

1) Updated common data repository.
2) Revised conceptual and numerical models.
3) Revised list of indicators of energy impacts on surface water resources.
4) Revised monitoring plans.
5) Interpretive report evaluating indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.

Phase III: Fully Implement Monitoring Program, Assessment, and Predictive Capabilities

Model results from Phase II will be evaluated in a regional context within Phase III. The areas that were modeled were deemed representative of the larger area of interest in Phase I. Given the results of the previous modeling work conclusions can be made that are relevant to the entire system. Additionally, during this phase of modeling the models will be adjusted to further explore the influence of anthropogenic changes on either parameters studied earlier or to examine new parameters.

Tasks

1) Implement revised nested monitoring program to fill data gaps and allow for upscaling and downscaling of results.
2) Implement revised trend-monitoring program for indicators.
3) Forecast regional effects of energy development on water resources.
4) Regular review of modeling results by an integrated team of managers, industry representatives, and scientists to keep parties informed and focused on management objectives.
5) Evaluate indicators relative to land health standards, surface-water quality standards, and other relevant health/management goals.
6) Identify corrective action needs.
7) Integrated team of managers, industry representatives, and scientists develop and implement corrective actions (Best Management Practices, BMPs).
8) Performance monitoring of BMPs.

Products

1) Updated common data repository.
2) Conceptual and numerical models that explain monitoring results in framework of controlling natural and anthropogenic factors.

3) Flexible and scalable monitoring program that assesses regional effects of energy development on water resources.
4) Best Management Practices.
5) Interpretive reports evaluating indicators relative to land health standards, surface water quality standards, and other relevant health/management goals.
6) Interpretive reports explaining monitoring results in framework of controlling natural and anthropogenic factors.

Conclusions

Achieving a fully implemented modeling program, as described in the example above, would provide detailed information on the effects of energy development on sediment production. However, financial constraints often limit how much work can be accomplished. With this in mind it is potentially beneficial to outline less demanding alternatives of modeling that will still provide valuable information. The modeling example described above is potentially the most detailed and informative. The coarsest alternative would be modeling only the White River, Piceance Creek or Yellow Creek watersheds to their outlets. An alternative of intermediate detail would be to monitor sediment at multiple points within one of the watersheds and the develop models able to account for sediment produced from the areas contributing to monitoring points. Regardless of which approach is selected it is imperative to understand that the success of both the monitoring program and the modeling are inter-dependent.

Example of Phase I : Integrate Existing Data and Models

Task 1: Using the tasks listed above it is possible to incorporate a modeling program into a monitoring project. The following example uses the Phase I tasks to illustrate the development of nested sediment transport models for areas within the Piceance Basin, specifically within the area of Colorado draining the White River. Within the White River Basin sediment transport will be examined for the White River drainage, the Piceance Creek subbasin and hillslopes within the Picenace Creek subbasin. The specific objective of the modeling is to estimate the seasonal and annual sediment yield produced at the outlet of each area. Incorporated into this effort will be the identification of how introducing roads and well pads will impact sediment production.

Task 2: Some of the spatial and temporal data readily available exists in the form of publicly available data produced by different agencies of the Federal Government.

a. Climate data is available from the National Weather Service at: http://www.ncdc.noaa.gov/oa/ncdc.html
b. Streamflow data, for Colorado, is available from the U.S. Geological Survey at: http://waterdata.usgs.gov/co/nwis/sw
c. Digital elevation data is available from the U.S. Geological Survey at: http://seamless.usgs.gov
d. Soil data is available from the Natural Resource Conservation Service at: http://soildatamart.nrcs.usda.gov

e. Landuse data is available from the U.S. Geological Survey at: http://www.mrlc.gov/mrlc2k_nlcd.asp

f. Maps of streams are available from the U.S. Geological Survey at: http://nhdgeo.usgs.gov/viewer.html

g. Sediment data is available from the U.S Geological Survey at: http://co.water.usgs.gov/sediment

In addition, data similar or identical to that listed above are available for the area from the state of Colorado at: http://cdss.state.co/DNN/Home/tabid/36/Default.aspx

Some of the data within the data repository will have accompanying maps/GIS coverages. Specifically, the digital elevation data, soil data, land use data, and stream maps will all be available in a format readily accepted by a GIS. It is essential; however, that each layer of spatial data be in the same projection. A common projection is the UTM projection although the Albers projection is often used due its ability to retain spatial accuracy. Temporal data, such as streamflow, climate and sediment information are often georeferenced to a specific point where the environmental variables are measured. These point data will most likely need to be created within the GIS. Coordinates for the measurement points often accompany the temporal data.

Task 3: The spatial and temporal boundary conditions of the model(s) are dependent on the environmental variable of interest; in this example the environmental variable is the sediment yield resulting form erosive processes. As the erosion of hillslope sediment is predominantly induced by precipitation it is reasonable to use topographic divides as the spatial boundary. Figure 8 depicts topographic boundaries for the White River and Piceance Creek watersheds.

Within the Piceance watershed 3 hillslopes would be identified; one hillslope where roads and well pads are to be introduced, a second with roads, and another relatively undisturbed hillslope. A hillslope is defined as an area of a watershed from the topographic divide to the stream. Ideally, the hillslopes are adjacent to one another and are similar, at least conceptually, in their hydrology. Three such hillslopes have been identified in the Horse Draw subbasin of Piceance Creek and are illustrated in Figure 8c and d. These hillslope models would allow for discerning between sediment produced naturally from the hillslope, the influence of roads only on sediment production, and the influence of well-pads and roads on the production of sediment.

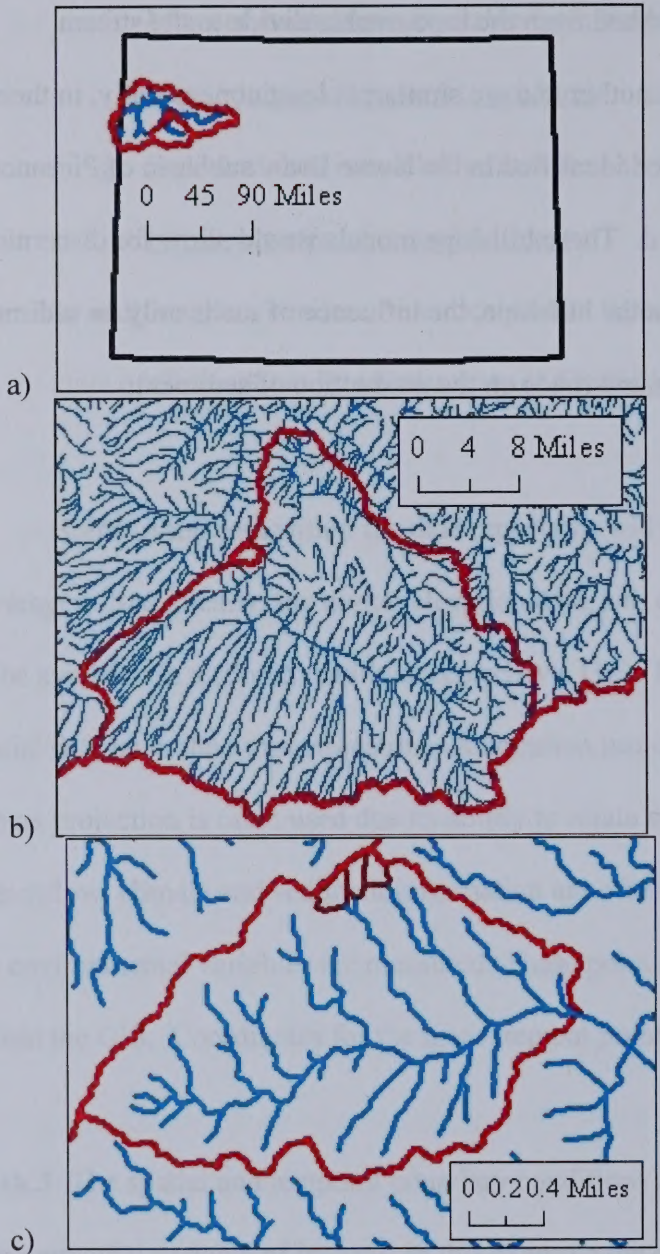

0 45 90 Miles
a)
0 4 8 Miles
b)
0 0.2 0.4 Miles
c)

Figure 10: Spatial boundaries of areas to be modeled are a) The White River and Piceance watersheds, b) the Piceance Creek and Horse Draw watersheds, c) the Horse Draw watershed and 3 hillslopes of the watershed, and d) the 3 hillslopes within the Horse Draw watershed underlain by an aerial photo of the area.

d)

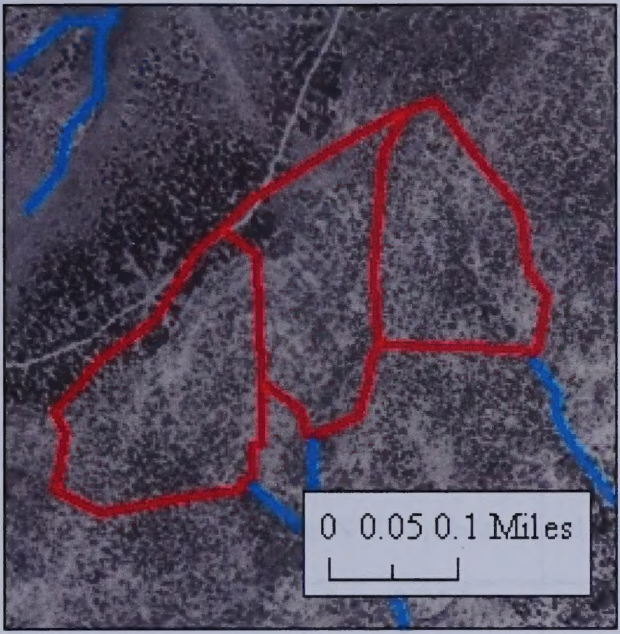


Figure 10: Spatial boundaries of areas to be modeled are a) The White River and Piceance watersheds, b) the Piceance Creek and Horse Draw watersheds, c) the Horse Draw watershed and 3 hillslopes of the watershed, and d) the 3 hillslopes within the Horse Draw watershed underlain by an aerial photo of the area. --CONTINUED

According to Yapo and others (1996) to adequately calibrate and validate a watershed model 8 years of temporal data are needed for each the calibration and validation. Periods shorter than this can fail to capture the interannual climatic variation that occurs. As the long-term effects of the energy development on environmental health are desired it is necessary that the models developed account for the varied conditions the system will experience. For watershed models like SWAT, the most common form of calibration data is streamflow measured at the outlet of the watershed being modeled. As Table 24 indicates there is enough data available at each the White River and Piceance Creek stream gages to allow for calibration and validation periods.

Table 24: Stream gage information for monitoring sites on the White River and at outlets of the Piceance and Yellow Creek watersheds.

Gage	Period of Record	Drainage Area (mi^2)	Mean annual Discharge (cfs)	Mean annual Discharge (inches)
White River near Watson, UT	04/01/1923 - Present	4,020	690.4	2.33
Piceance Creek at White River, CO	10/01/1964 - Present	652	35.6	0.74

Ideally the models developed for each watershed would use the same time periods for the calibration and validation periods. The calibration period does not have to precede the validation period because it is assumed each period encompasses the same variability. Because there is daily suspended sediment data available at the Piceance stream gage during the period from 4/1/1974-9/30/1982 this period will be used to calibrate the models. The benefit of using this period for calibration is that the models can be calibrated to streamflow and sediment yield. No data exists from a prior period to examine erosion from hillslopes, which is why the three hillslope approach would be used; they would represent pristine and altered states. The temporal boundary for the WEPP model consequently would be the length of the monitoring project.

Task 4: Developing a general mass balance for the system to be modeled allows the scientist doing the modeling a chance to become familiar with the area and the potential environmental processes at work. In addition a general mass balance provides some general conditions with which to evaluate initial model performance. For the modeling within the White River and Piceance Creek watersheds estimates of the water balance would be obtained. Values of long-term, mean annual values of precipitation, streamflow, and evapotranspiration could constitute a coarse water balance and are readily attainable from Internet based geodatabases and literature sources. Precipitation data can be obtained from numerous weather stations in and around the White River watershed using the NWS website listed above. Using data from 9 stations and with a minimum period or record of 18 years and a maximum of 64 years a mean annual value of 13.7 inches of precipitation was derived. Mean annual estimates of streamflow can be obtained from the USGS website listed above. Using those sources the mean annual values for streamflow from each watershed were obtained and are presented in Table 24. Evapotranspiration losses are the hardest to estimate and although estimates of actual evapotranspiration are available in some places generally estimates are obtained by adjusting estimates of potential evapotranspiration (PET) or through using literature sources. For Piceance Creek two water balances were obtained from available literature. The BLM (BLM, 2006) and Wymore (1974) each developed mean annual water balances for the Piceance Creek watershed. A summary of the published mass balances and the precipitation and streamflow estimates described above is presented in Table 25.

Table 25: Comparison of mass balance values presented by Wymore (1974), the BLM (2006), and those obtained via the Internet.

	Piceance Creek		
	Wymore	BLM	Online
Precipitation	13.89	15.5	13.74
Streamflow	0.39[a]	0.74[b]	0.74
Evapotranspiration	17.01	42.5[c]	

a. Presented as a summation of streamflow and percolation.

b. Presented as minimums and maximums, but used the same data as that collected online.

c. Presented as 40-45 inches and is an estimate of PET rather than actual evapotranspiration.

Task 5: Using the mass balance and field observations it is possible to arrive at a general conceptual understanding of the environmental processes occurring. An example of how this might be accomplished will be presented that considers that data available for Picenace Creek. From the mass balance it is apparent that evapotranspiration exceeds precipitation on an annual basis. Intuitively then, contributions to streamflow from groundwater must be important because the water flows perennially (Figure 11). From the day to day variability in the daily hydrograph, however it is evident that quicker flow paths exist. The lack of correlation between precipitation and streamflow, which is indicative of surface runoff that occurs when precipitation rates exceed the infiltration rate of the soil (Hortonian flow), suggests that hydrograph peaks are caused by shallow subsurface pathways (Figure 10). As a result of the freeze/thaw action occurring in the area throughout the winter more of the snowmelt would infiltrate taking a more circuitous route to the stream than if it were to travel directly over the surface. The sediment data can also be used to help develop the conceptual understanding of the environmental processes. When comparing the observed suspended sediment and streamflow data, as in Figure 9, it is apparent that increases in suspended sediment generally correspond to increases in streamflow. Intuitively erosion occurs at the surface. For erosion to occur then it follows that surface runoff must also occur. Because of the lack of correlation between precipitation and streamflow and the occurrence of erosion it is probable that surface runoff is occurring through a saturation excess process. Saturation excess runoff occurs when the soil becomes saturated such that any further received precipitation is unable to infiltrate and must run over the surface. This conclusion has further implications in that it can be assumed that the area of the watershed contributing sediment to the streams corresponds to areas that reach saturation following a precipitation event. Generally these areas are in relative proximity to the stream. It should be noted that although this example may represent the hydrologic processes occurring it is provided more as a demonstration as to what the modeler should consider when developing a conceptual hydrology.

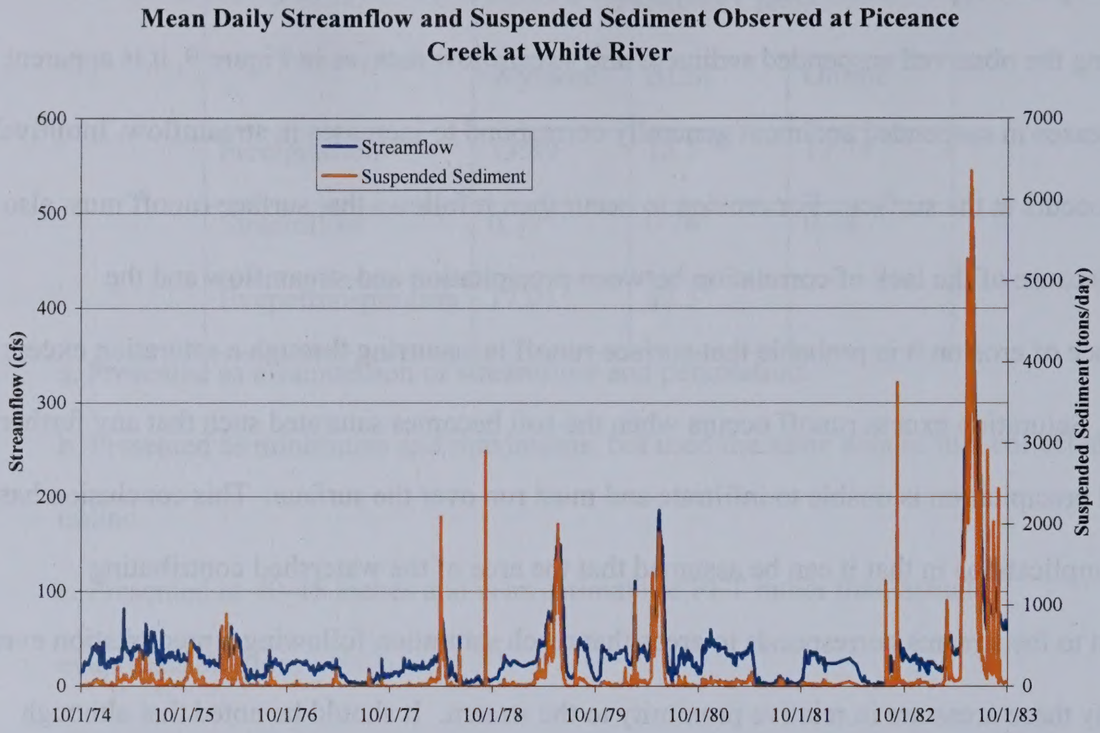
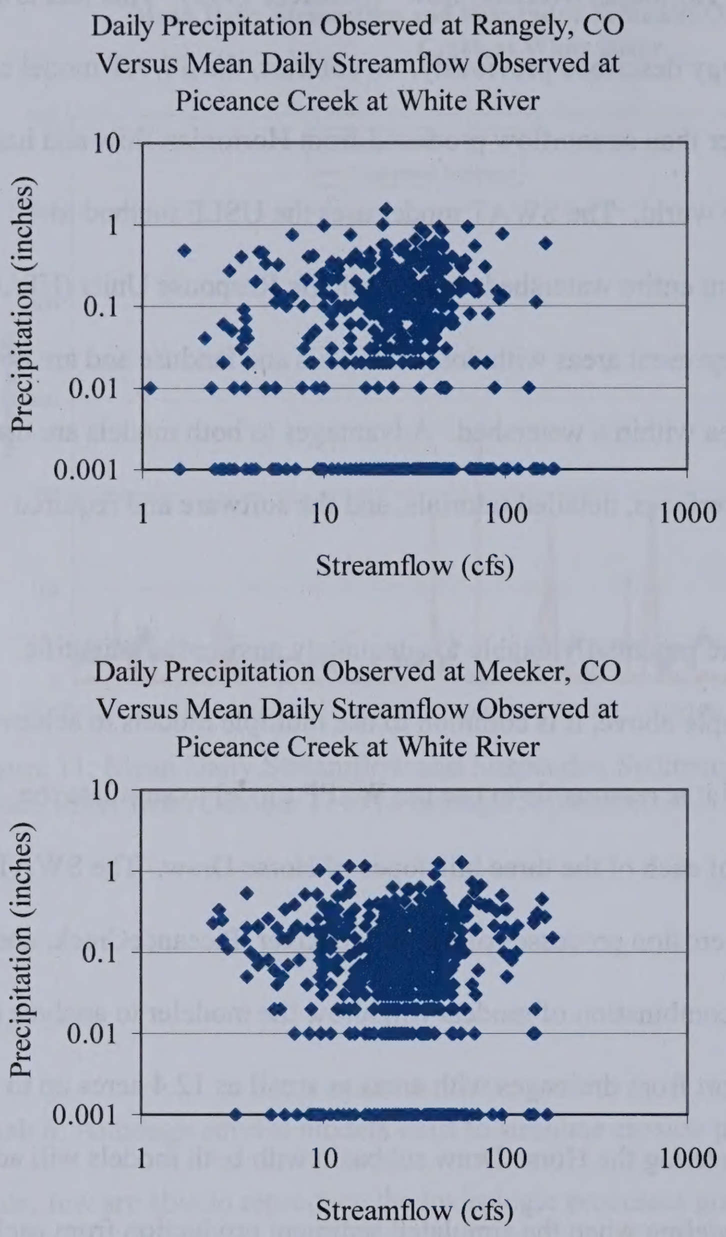


Figure 11: Mean Daily Streamflow and Suspended Sediment Observed at Piceance Creek at White River from October 1, 1974 through September 30, 1983.

Task 6: Although several models exist to simulate erosion processes at a hillslope and watershed scale, few are able to reproduce the hydrologic processes governing streamflow production. Two potential models able simulate such processes are the Water Erosion Prediction Project (WEPP) model (Flanagan and Livingston, 1995) and the Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1995). The WEPP model represents the most contemporary, physically based model for simulating erosion processes for watersheds and their hillslopes. It was designed to replace the Universal Soil Loss Equation (USLE)(Wischmeier and Smith, 1978) as the preferred method for estimating erosion. Use of the WEPP model "is limited to areas where the hydrology is dominated by Hortonian overland flow" (NSERL, 1995). This fact is a concern given the conceptual hydrology described previously. In contrast, the SWAT model can account for hydrologic processes other than streamflow produced from Hortonian flow and has been applied to watersheds across the world. The SWAT model uses the USLE method to simulate erosion at scales varying from entire watersheds to Hydrologic Response Units (HRUs). Within SWAT, HRUs are meant to represent areas with dominant soils and landuse and are not explicitly attributable to a specific area within a watershed. Advantages to both models are that they have friendly Graphical User Interfaces, detailed tutorials, and the software and required data are available Online for free.

When the models identified are potentially unable to adequately answer the scientific questions being asked, as in the example above, it is common to use multiple models to achieve the desired results. With this in mind it is reasonable to use the WEPP model to simulate the specific hilllslope erosion processes of each of the three hillslopes of Horse Draw. The SWAT model would be used to simulate the erosion processes of the White River, PiceanceCreek, and Horse Draw watersheds. Using this combination of models will allow the modeler to analyze the processes governing sediment transport from drainages with areas as small as 12.4 acres up to the 4,020 mi^2 of the White River. Modeling the Horse Draw subbasin with both models will add an aspect of quality control to the modeling when the simulated sediment production from each model is compared.



Daily Precipitation Observed at Rangely, CO Versus Mean Daily Streamflow Observed at Piceance Creek at White River

Daily Precipitation Observed at Meeker, CO Versus Mean Daily Streamflow Observed at Piceance Creek at White River

Figure 12: Comparisons of mean daily streamflow observed at Piceance Creek at White River from October 1, 1974 through September 30, 1983 to daily precipitation observed at a) Rangely, CO and b) Meeker, CO during the same time period.

Task 7: Creating the models requires intimate knowledge of the (1) geospatial and temporal data available, (2) preprocessors used to convert data to the format used by the model, (3) physics of the potential environmental processes and how the model accounts for them, (4) methods of sensitivity analysis, (5) and methods of calibration and validation. Because the SWAT and WEPP models will be designed to simulate sediment yields seasonally and annually it is not necessary to ensure the daily climatic spatial variability is explicitly accounted for in the model. The coarse time scale also allows the modeler to use weather generators that are available with each model, although the simulated climate should be compared to climate data available from stations in around the basin to ensure consistency.

Becoming familiar with a preprocessor can take a considerable amount of time, on the order of weeks to months. Although the details of the preprocessors used for SWAT and WEPP are too numerous to recount in this document, both require experience with manipulating spatial data using a Geographic Information System. Fortunately, tools are available with each model to obtain the required spatial data, which limits errors that might occur due to incorrect formats.

To understand the theory behind the sediment transport processes simulated by SWAT and WEPP it is necessary that the modeler have a detailed understanding of the physics of erosion and hillslope and watershed hydrology before reading each models documentation. This knowledge is invaluable if the models are calibrated manually because the modeler will understand how different processes interact with each other and can logically adjust parameters. Additional knowledge of possible values for parameters, such as hydraulic conductivity, *a priori* can ensure model parameters are constrained within reasonable limits.

Calibration of the models can be a very time consuming processes depending on the complexity of the hydrologic processes occurring and model being used. Models can have numerous parameters so it is common to conduct a sensitivity analysis to identify to what degree parameters influence a model. Often the sensitivity analysis is automated. Through extensive use of the model, literature reviews and a conceptual understanding of the environmental processes, though, the most sensitive parameters can often be identified. Following the sensitivity analysis the models could be either manually or automatically calibrated. Manual calibrations can be laborious, especially if the modeler is unfamiliar with the models sensitive parameters. The benefit of manual calibration is that the scientist becomes very confident with the workings of the models, the system being modeled, and the results produced by the models. Automatic calibration can decrease the time required to identify sensitive parameters and calibrate the model. It is essential that the scientist be very familiar with the mathematical and statistical manipulations used by an automatic method of calibration to avoid the acceptance of parameter sets that may inadequately represent the environmental processes occurring. Both calibration and validation are discussed in more detail by Beven (2001) and Abbott and Refsgaard (1996).

Tasks 8-10: From the modeling experience gained so far it may be apparent that either the conceptual understanding of environmental processes occurring was flawed, or the models did not perform as hoped, or there was insufficient data to adequately examine the processes occurring. It should be apparent to the modeler what environmental parameters are sensitive in the system and, correspondingly, what monitoring should be introduced or enhanced to improve model performance. Upon realizing what adjustments are required, the modeler should coordinate with resource managers so that they are aware of what is needed to best use the modeling tools.

Integration of the Regional Monitoring Framework

(NOTE TO REVIEWER: If the following example illustrations are accepted as an approach to illustrate the integrated workings of the Regional Frame work. This sequence of figures will be expanded to encompass the multiple interrelationships between water-resource disciplines.)

An initial example of integration of different water-resources disciplines is given in figures 13 and 14. In figure 13 a conceptual model of the process of introducing sediment into the hydrologic system if outlined. The integration of sediment availability into the cumulative effects of multiple stressors, including energy development, is represented in figure 14. The introduction of sediment into the hydrologic system is related to effects on the aquatic ecosystem and associated biota. In addition, these processes can be related to instream sediment standards implemented under the Clean Water Act as described in the section “Stream Biology Resource Monitoring Related to Energy Development”. In addition the definition of sediment availability can be applied to instream water quality, channel morphology, and effects on lakes and reservoirs.

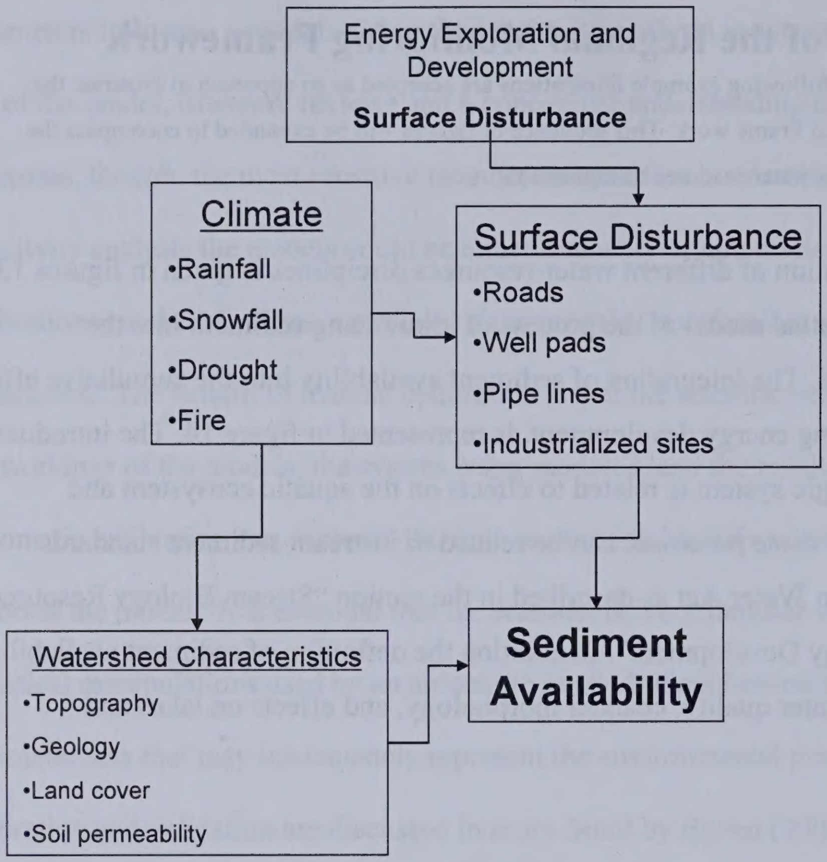

Energy Exploration and Development
Surface Disturbance
Climate
•Rainfall
•Snowfall
•Drought
•Fire
Surface Disturbance
•Roads
•Well pads
•Pipe lines
•Industrialized sites
Watershed Characteristics
•Topography
•Geology
•Land cover
•Soil permeability
Sediment Availability

Figure 13. Conceptual model of the cumulative effects of energy exploration and development on sediment availability.

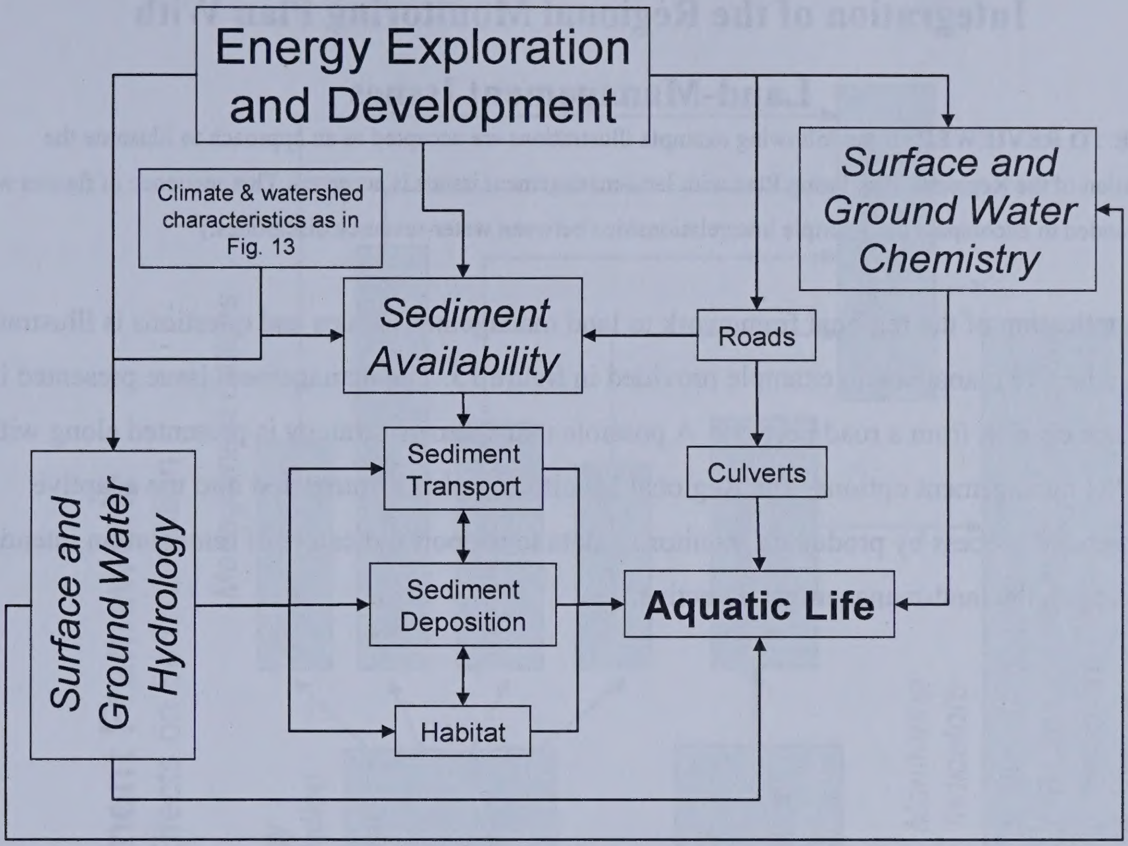

Energy Exploration and Development
Climate & watershed characteristics as in Fig. 13
Surface and Ground Water Chemistry
Sediment Availability
Roads
Sediment Transport
Culverts
Surface and Ground Water Hydrology
Sediment Deposition
Aquatic Life
Habitat

Figure 14. Conceptual model of the cumulative effects of energy exploration and development related disturbances to aquatic life. Italicized text indicates potential major stressors on aquatic life conceptually modeled in later figures.

Integration of the Regional Monitoring Plan With Land-Management Issues

(NOTE TO REVIEWER: If the following example illustrations are accepted as an approach to illustrate the integration of the Regional Monitoring Plan with land-management issues is accepted. This sequence of figures will be expanded to encompass the multiple interrelationships between water-resource disciplines.)

The application of the regional framework to land management issues and questions is illustrated in the adaptive management example provided in figure 15. The management issue presented is to reduce erosion from a road network. A possible management strategy is presented along with potential management options. The Regional Monitoring plan is integrated into the adaptive management process by producing monitoring data to support indicators of remediation intended to addresses the land-management objective.

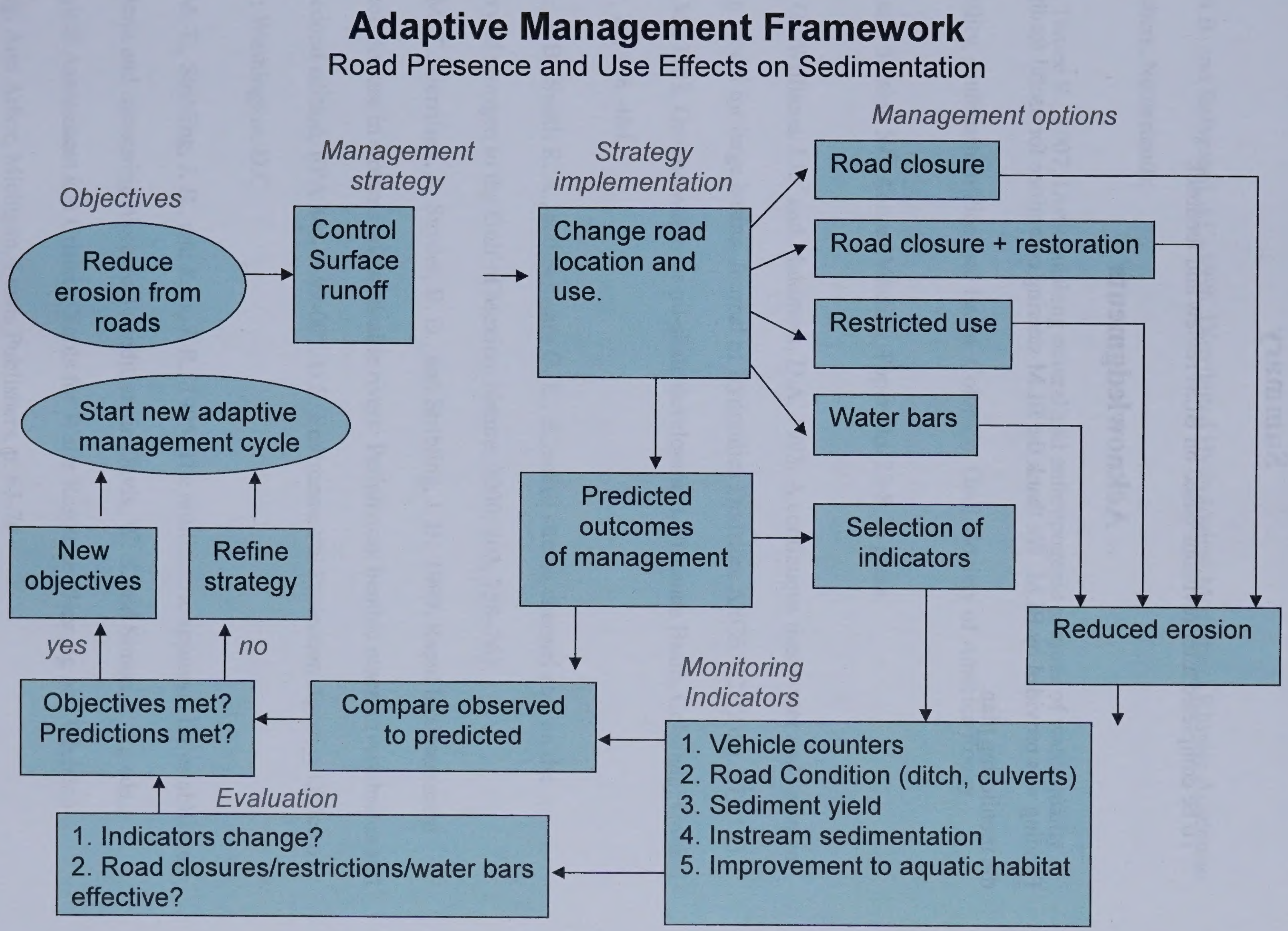

Adaptive Management Framework
Road Presence and Use Effects on Sedimentation
Objectives
Reduce erosion from roads
Management strategy
Control Surface runoff
Strategy implementation
Change road location and use.
Management options
Road closure
Road closure + restoration
Restricted use
Water bars
Reduced erosion
Start new adaptive management cycle
New objectives
Refine strategy
Predicted outcomes of management
Selection of indicators
yes
no
Objectives met? Predictions met?
Compare observed to predicted
Monitoring Indicators
1. Vehicle counters
2. Road Condition (ditch, culverts)
3. Sediment yield
4. Instream sedimentation
5. Improvement to aquatic habitat
Evaluation
1. Indicators change?
2. Road closures/restrictions/water bars effective?

Figure 15. Adaptive management framework applied to strategies to mitigate sediment production from roads.

Summary

To be completed after revisions based on BLM review and feedback

Acknowledgments

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